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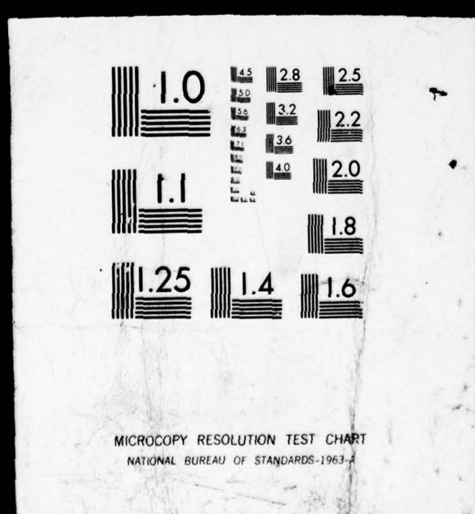

DEPARTMENT OF THE AIR FORCE
HQ Air Force Communications Service
Richards-Gebaur AFB, Missouri 64030

DCS OPERATIONAL

TEST AND EVALUATION

OF

PULSE CODE MODULATION/TIME DIVISION MULTIPLEX (PCM/TDM) EQUIPMENT

Test Report
August 1973 - February 1974

UNCLASSIFIED

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This report expands the investigation of overhead channel performance, VF channel assessment and system performance monitoring.

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DCS OPERATIONAL TEST AND EVALUATION OF PCM/TDM EQUIPMENT

ABSTRACT

This report documents results obtained in the test and evaluation of off-the-shelf commercial Pulse Code Modulation/Time Division Multiplexing (PCM/TDM) equipment suitable for use in Defense Communications Systems (DCS) upgrades and future DCS digital systems. In order to develop an adequate operations and maintenance capability which will insure that the performance of digital transmission systems meets or exceeds that of existing analog systems, it is required that comprehensive investigation be made in the areas of effective performance assessment techniques, quality overhead channel provisions and efficient maintenance concepts.

The tests conducted during this period address system performance assessment techniques at the baseband and voice frequency levels and an overhead channel insertion technique.

This report presents the overall objectives of system performance assessment. Included is a detailed description and analysis of the technique employed in the test facility for degradation monitoring at the baseband input to the high speed (12.6 Mbps) Time Division Multiplex. The voice frequency channel performance tests investigated in-service and out-of-service quality tests and the development of a single, common measuring technique. The results presented on the overhead channel investigation reflect comprehensive evaluation of overhead channel filter characteristics and their effects on the quality of the digital signal.

An additional inclusion in this report is a proposed maintenance concept for baseline development of refined and comprehensive procedures to be employed in actual field use.

DCS OPERATIONAL TEST AND EVALUATION OF PCM/TDM EQUIPMENT

LIST OF ABBREVIATIONS

AGC . . . . Automatic Gain Control
AGE . . . . Aerospace Ground Equipment (Test Equipment)
BB . . . . Baseband (0-10 MHz Radio/Multiplex Interface)
BER . . . . Bit Error Rate
BF_t . . . . D-2 Frame Bit (terminal)
BITE . . . . Built-In Test Equipment
CIMF . . . . Central Intermediate Maintenance Facility
C/N . . . . Carrier-to-Noise Ratio
DCS . . . . Defense Communications System
FDM-FM . . . . Frequency Division Multiplex-Frequency Modulation
IF . . . . Intermediate Frequency
LPA . . . . Link Performance Assessment
LRU . . . . Line Replacement Units
MOR . . . . TDM-to-Overhead Channel Power Ratio
MTBF . . . . Mean Time Between Failure
MWC . . . . Maintenance Work Center
NRZ . . . . Nonreturn to Zero
NSA . . . . National Security Agency
OHC . . . . Overhead Channel
O&M . . . . Operations and Maintenance
PCM/TDM . . . . Pulse Code Modulation/Time Division Multiplex
PLL . . . . Phase Lock Loop
PMEL . . . . Precision Measurement Equipment Laboratory
PMI . . . . Preventive Maintenance Instruction
RF . . . . Radio Frequency
RSL . . . . Radio Signal Level
S/N . . . . Signal-to-Noise (Ratio)
TCF . . . . Technical Control Facility
VF . . . . Voice Frequency

NOTE: Some of these abbreviations are applicable only to this particular test. Future tests will use the approved abbreviations contained in AFM 11-1, Volumes 1 and III and AFM 11-2.

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Chapter 1

INTRODUCTION

1-1. Objectives. The Digital Network Systems Facility, formerly PCM/TDM Test Bed, was established by the Air Force Communications Service to contribute to the Air Force capability for supporting future C-E programs which introduce digital communications into the Defense Communications System. Long-range objectives seek to provide the following:

a. Identification of requirements for engineering, implementation, operating and maintaining a digital network, including an appraisal of performance assessment and the related operations and maintenance procedures.

b. Timely input for use in planning and development of future DCS systems employing digital communications techniques.

1-2. Test Efforts. Since commissioning, immediate efforts have focused on link performance assessment, fault isolation, and development of a technical management capability. Initial testing was directed towards optimizing FM radios for digital operation, verifying an overhead channel capability, interfacing the 4 kHz audio channel and investigating test points for system performance assessment. These efforts were covered in the 6 September 1973 test report published by HQ AFCS entitled, DCS Operational Test and Evaluation of PCM/TDM Equipment. Since then, test objectives have addressed the same theme while

expanding the investigation of overhead channel performance, VF channel assessment and system performance monitoring.

1-3. Contents. The following chapter contains a summary of the results of tests performed during the period August 1973 through February 1974. These tests have focused specifically on the development of common VF channel measuring techniques, characterization of the VF channel, evaluation of overhead channel filters, and the evaluation of TDM performance under variations of the baseband input signal level.

a. Chapter 3, System Performance Monitoring, presents the objectives of system performance/degradation monitoring together with a discussion of the basic requirements necessary to insure effective performance monitoring and fault isolation. This philosophy and preliminary conclusions will subsequently direct the evolution of a prototype monitoring system within the AFCS Digital Network Systems Facility. In chapter 4, Systems Maintenance Proposal, a generalized maintenance concept is outlined. This concept is predicated on the ability to effectively fault isolate and performance monitor digital transmission networks.

b. The final chapter, Conclusions/Recommendations, consolidates significant work and test efforts to date. Recommendations, where pertinent, are also provided.

c. Attachment 1 describes the geographical layout of the AFCS Digital Network Systems Facility, with a description of the major installed equipment and the end-to-end PCM signal flow. Specific test objectives, detailed test procedures, and the presentation of test data are included in Attachments 2 through 4. Attachment 5 details the operation of the AFCS performance monitoring equipment. Attachment 6 provides for reference the mathematical relations used in developing the proposed maintenance concept.

Chapter 2

SUMMARY OF TEST RESULTS

2-1. <u>Introduction</u>. The general rationale and significant results of the tests performed during the period August 1973 through February 1974 are presented in this chapter. Specific details of test procedures, equipment configuration, and data analysis are contained in the attachments.

2-2. <u>VF Channel Assessment</u>.

a. In frequency division multiplex (FDM) systems, the quality of voice frequency (VF) channels is determined by a series of independent tests which include idle channel noise, phase jitter, harmonic distortion, intermodulation distortion, crosstalk, and impulse noise. These measurements under normal conditions can also determine the quality of a VF channel in a PCM/TDM system.

b. Quantizing distortion, resulting from analog-to-digital conversion, is an additional measure of channel quality in a PCM/TDM system. The VF channel assessment series of tests were designed to apply the commonly used FDM measuring technique, developing an efficient in-service test procedure, and evaluating an out-of service test procedure, and evaluating an out-of-service quality check which would aid fault isolation.

(1) *Common Measuring Technique*. VF channel distortion measurements (phase jitter, harmonic distortion, intermodulation, quantizing distortion)

are, with the exception of phase jitter, similar measuring techniques. Each requires a test tone to be inserted into the channel and each requires special test equipment. A common measuring technique was tested which attempted to provide a single qualitative measure (figure of merit) of signal distortion in a TDM VF channel. This technique, detailed in Part One of Attachment 2, uses a phase jitter meter and an RMS voltmeter to obtain a direct measure of phase jitter and an indirect approximate measure of signal-to-noise ratio. Signal-to-noise related readings are read directly from the voltmeter connected to the analog output of the phase jitter meter. Extensive measurements at varying test tone levels were made to compare this signal-to-noise (S/N) ratio with harmonic distortion and quantizing distortion.

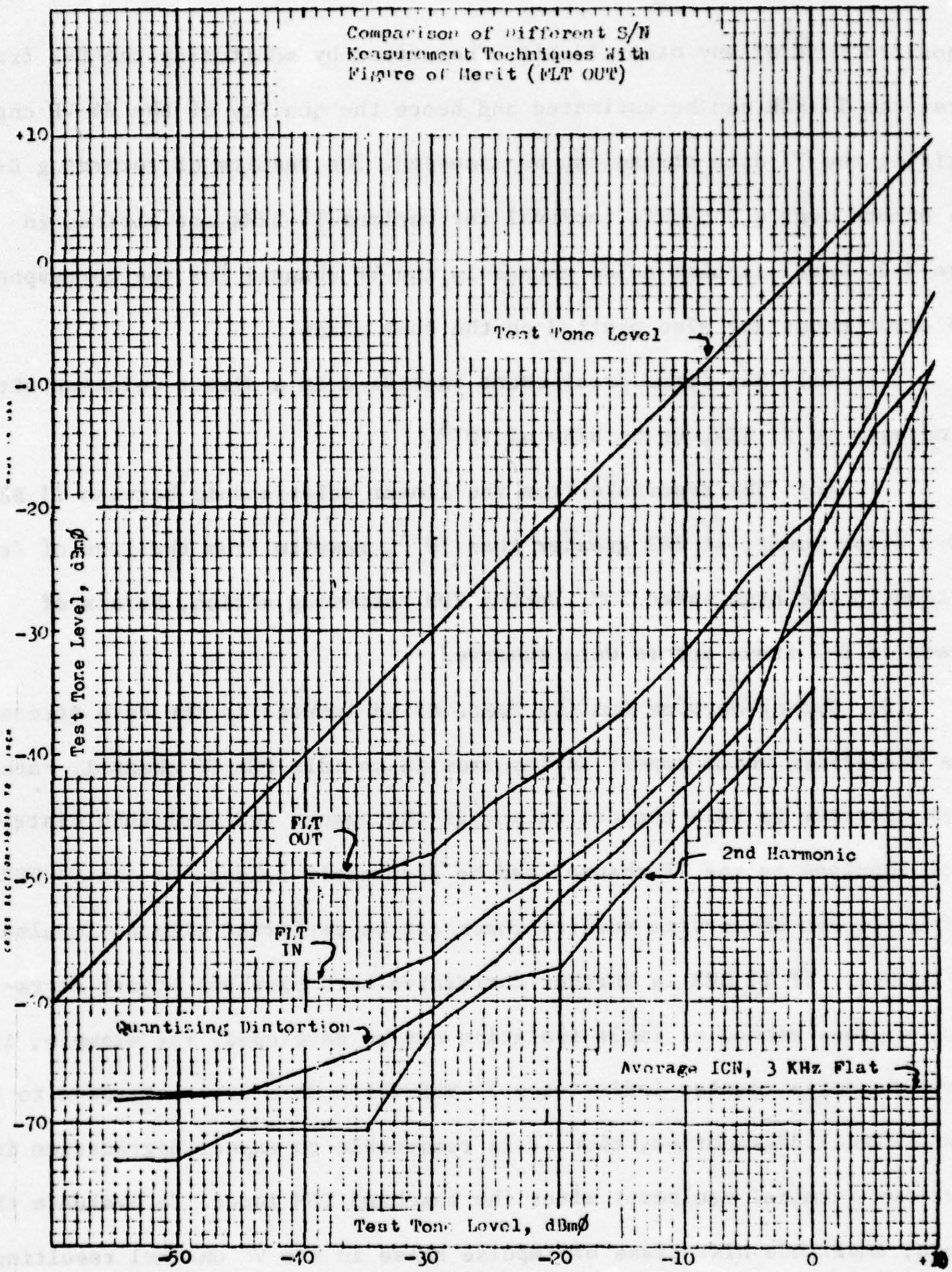
(a) Figure 2-1 shows the following summary of results:

1. Over the range of test tone (1020 Hz) levels from 0 dBm Ø to -20 dBm Ø, the figure-of-merit and harmonic distortion measurements bear an approximate linear relationship; with harmonic distortion approximately 15 dB down from the figure-of-merit readings.

2. Quantizing distortion is 3 dB down from the figure-of-merit value of 0 dBm Ø; the difference however, increases to 16 dB at the test tone level of -40 dBm Ø.

3. There is no significant relationship between the figure-of-merit values and idle channel noise readings.

(2) *In Service Test Technique.* The approach used to develop an in-service test technique depends on correlating the T1 BER with the D-2 channel bank frame error indications. Theoretically, D-2 frame errors should be directly related to T1 bit errors because the probability of a frame bit being in error



Comparison of Different S/N
Measurement Techniques With
Figure of Merit (FLT OUT)
Test Tone Level, dBm0
Test Tone Level
FLT OUT
FLT IN
2nd Harmonic
Quantising Distortion
Average ICN, 3 KHz Flat
+10
0
-10
-20
-30
-40
-50
-60
-70
-50
-40
-30
-20
-10
0
+10

Figure 2-1.

is equal to that of any other T1 bit. Therefore, by monitoring the D-2 frame errors, the T1 BER can be estimated and hence the quality of the 24 VF channels comprising the T1 data stream can be assessed. The results of recording D-2 frame errors over a 5 minute interval for various T1 BERs are plotted in Figure 2-2. Total impulse noise counts in the VF channel for the corresponding frame error count are also plotted on the same graph.

(a) The frame error count increases in a direct relation with the increase in T1 BER, up to BERs of 10^{-5}.

(b) The departure from the linear relationship between T1 BER and D-2 error count, at BER greater than 10^{-5}, results from the loss of frame condition in the high speed TDM. During TDM reframing action, bursts of hundreds of D-2 frame errors were observed.

(3) *Out-of-Service Quality Test.* Noise induced in the data stream causes bit errors which appear as impulses in an idle PCM VF channel, rather than an increase in idle channel noise. If the number and amplitude distribution of impulses in the VF channel can be accurately related to the T1 BER, an effective out-of-service quality check can be performed with an impulse noise counter. If T1 BER is further correlated with baseband signal degradation, a gross method of fault isolation can be developed. For example, if the impulse noise counter indicates a T1 BER which does not correspond to the baseband signal degradation, then it is reasonable to expect degradation in the receive terminal equipment after the baseband TDM input. To evaluate this approach, amplitude histograms of impulse noise in the VF channel resulting from varying T1 BERs were recorded and analyzed. Simultaneously, the TDM baseband S/N ratio was also recorded (Figure 2-4). Detailed procedures are

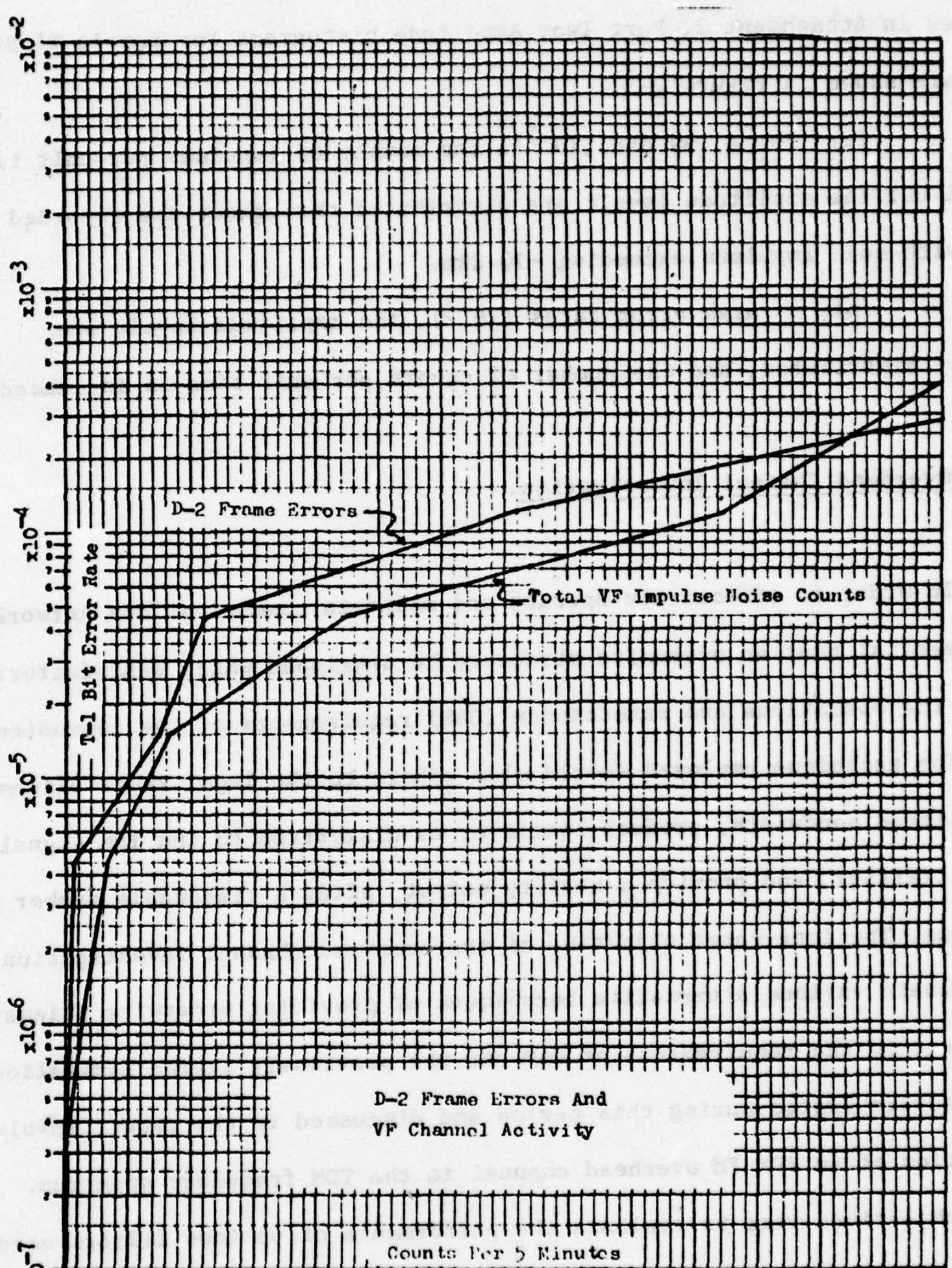

D-2 Frame Errors
Total VF Impulse Noise Counts
T-1 Bit Error Rate
D-2 Frame Errors And
VF Channel Activity
Counts Per 5 Minutes
x10^-2
x10^-3
x10^-4
x10^-5
x10^-6
x10^-7
100
200
300
400
500
600
700

Figure 2-2.

contained in Attachment 2, Part Two. Amplitude histograms for sample T1 BERs tested are shown in Figure 2-3.

(a) For a low BER (10^{-7}), the number of impulses per unit time is small but the amplitude levels are distributed throughout the recorded range, with some impulses exceeding -10 dBm.

(b) At high error rates (10^{-3}), the amplitude levels are similarly distributed, and the number of counts per unit time is increased.

2-3. Overhead Channel Investigation.

a. In order to effectively operate and maintain communications networks, it is essential that an orderwire structure be developed which satisfactorily supports the operations and maintenance (O&M) requirements of the communications system. The technique employed should also adhere to the legal restrictions of transmitted bandwidth, produce little or no distortion to the TDM signal (mission traffic), and provide a quality output after a reasonable number of tandem hops. The long-range objective of the overhead channel investigation is to evaluate various alternative techniques of providing orderwire telemetry with respect to the requirements of O&M and the previously stated limitations. The alternative tested during this period and discussed in the report involves the insertion of an FDM FM overhead channel in the TDM frequency spectrum. Specific objectives were to evaluate the performance of various filters used to insert an overhead channel in the high end of an 8-port TDM partial response baseband spectrum which is then transmitted over a Motorola MR-300 microwave radio link.

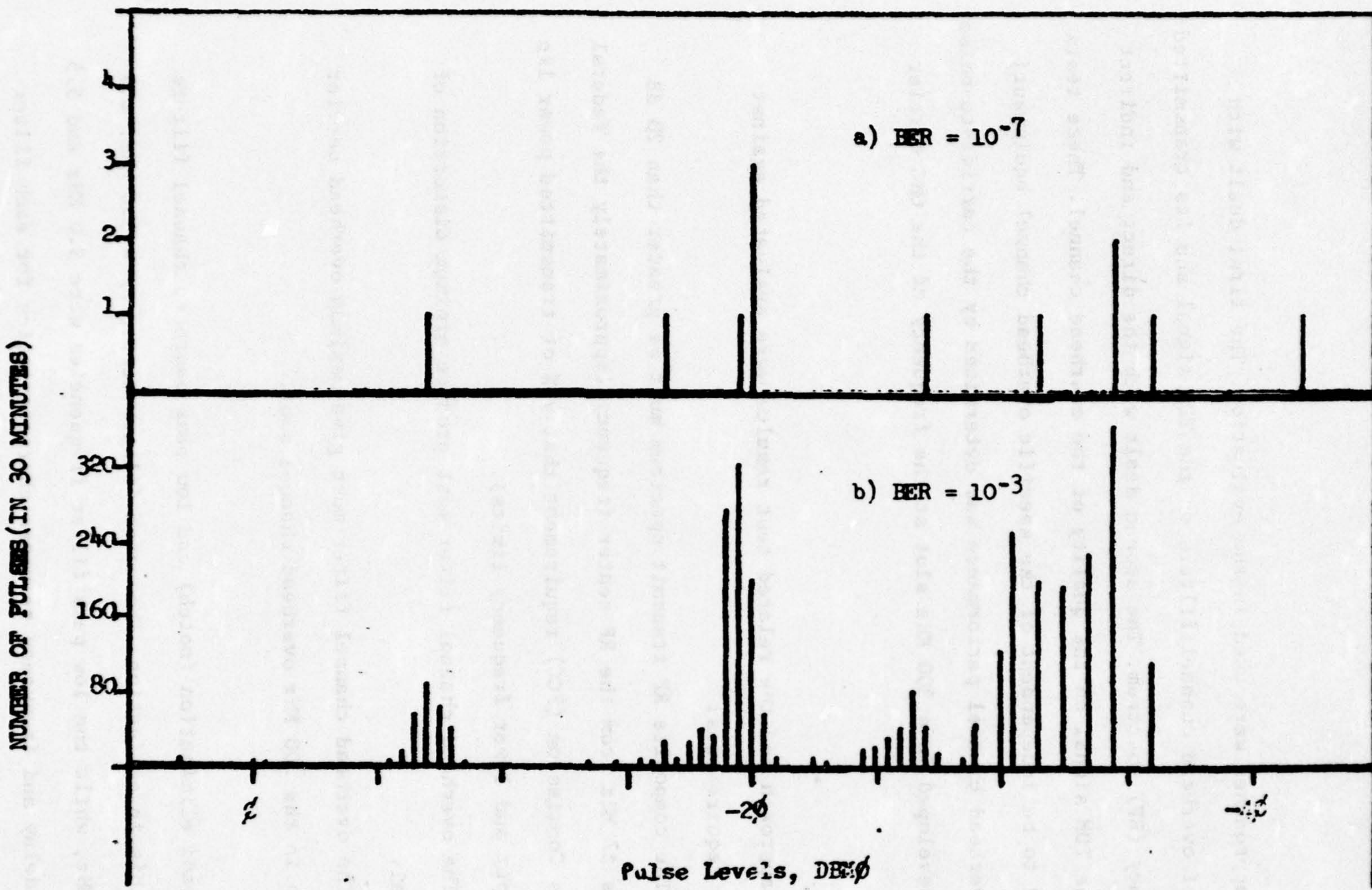


Figure 2-3

VF Channel Impulse Noise

b. Two approaches were used in the evaluation. The first dealt with the effects of overhead channel filters on the TDM signal and its transmitted radio frequency (RF) spectrum. The second dealt with the direct and indirect effects of the TDM signal on the quality of the overhead channel. These tests were designed to be independent of the specific overhead channel equipment; therefore, overhead channel performance was determined by the carrier-to-noise (C/N) ratio developed in a 200 KHz slot at the frequency of the OHC carrier under study.

c. Each approach and the related test results were evaluated against the following requirements:

(1) The composite RF transmit spectrum must be greater than 20 dB down at points ±7 MHz from the RF center frequency (approximately the Federal Communications Commission (FCC) requirement that 99% of transmitted power lie within the upper and lower frequency limits).

(2) The overhead channel filter must produce minimum distortion of TDM data signal.

(3) The overhead channel filter must give maximum overhead carrier to noise ratio in the 200 KHz overhead channel slot.

d. Both band elimination (notch) and low pass overhead channel filters were used in this investigation. The notch filters tested were 6.8 MHz, 6.9 MHz, and 7.5 MHz, while the low pass filter frequencies were 5.0 MHz and 5.5 MHz. Envelope delay and frequency response characteristics for each filter are provided in Attachment 3. The specific tests are briefly described below.

(1) *Filter Characteristics*. The baseband characteristics, frequency response, and envelope delay were photographed with the TDM signal through the transmit overhead channel filter, through the receiver overhead channel filter, through both the transmit and receiver filters back to back, and through both filters over the MR-300 radio link. Qualitative determinations of TDM signal quality were made by photographing the signal distortion introduced in the TDM eye pattern and by recording the extent of signal degradation reflected on the degradation monitor. (Degradation monitoring equipment is explained in Attachment 5.) Definite relationships exist between the filter characteristics (frequency response and envelope delay) and degradation of the TDM performance. Figures 2-5 and 2-6 show the characteristics of the least degrading (6.9 MHz notch) and the most degrading (5.0 MHz low pass) overhead channel filter. The 6.9 MHz filter, designed to provide delay equalization, produced the least distortion to the TDM eye pattern.

(2) *Transmit RF Spectrum*. To evaluate transmit bandwidth occupancy, two microwave radio parameters were varied. First, at a modulation index of 0.5, the TDM-to-overhead channel power ratio was varied over the range of 30 dB to -5 dB in 5 dB steps. For each variation X-Y plots of the RF transmit spectrum were recorded. Second, using the 7.5 MHz notch filter, the radio modulation index was varied from 0.2 to 1.0. RF spectrum plots were also recorded for each modulation index. A summary of the test results revealed:

(a) Of the filters tested the 6.9 MHz notch filter came closest to meeting the established RF transmit bandwidth. Figure 2-7 shows the typical response of this filter for the MOR range tested. The remaining RF spectrum plots are contained in Attachment 3.

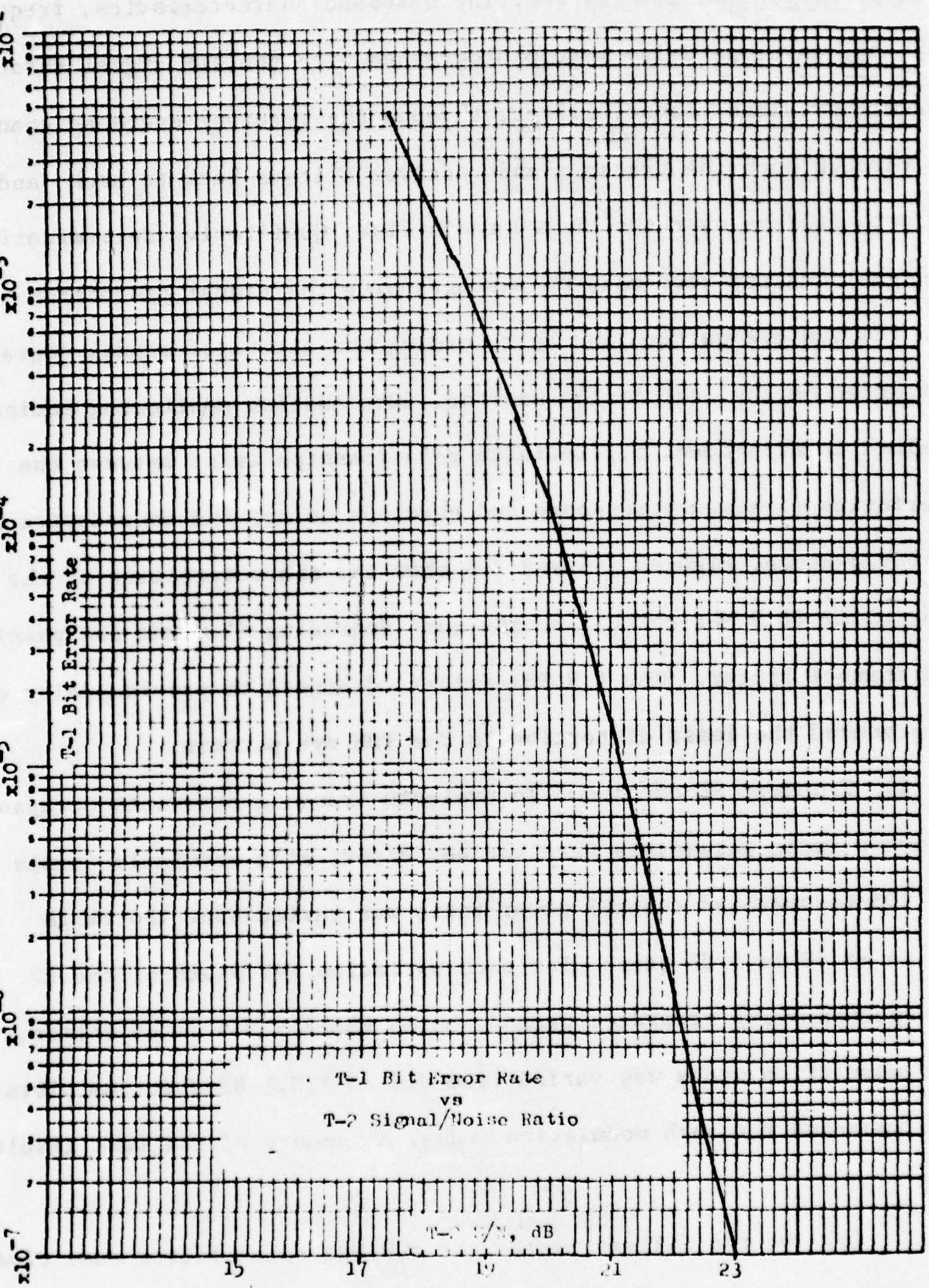
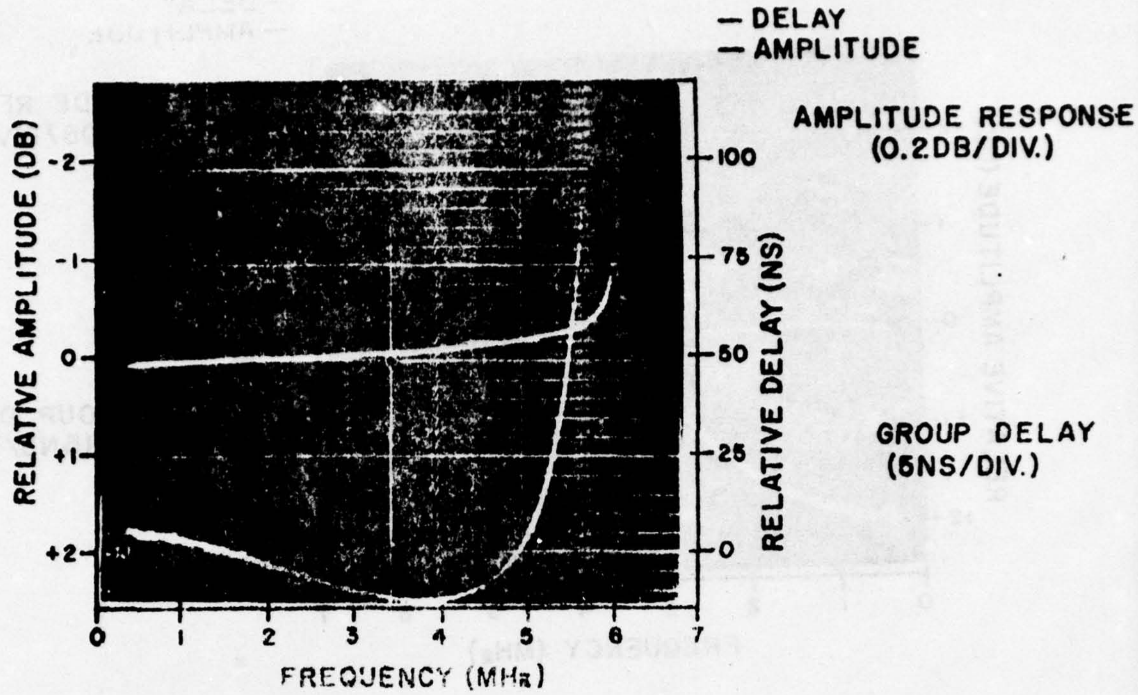
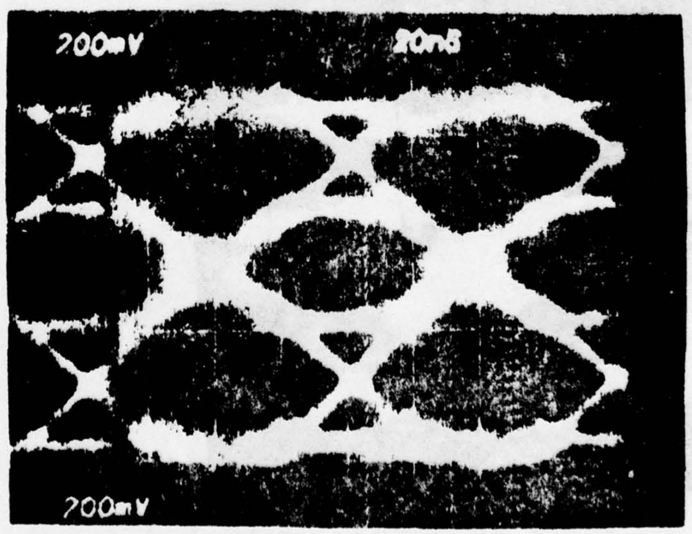

T-1 Bit Error Rate
T-1 Bit Error Rate
vs
T-2 Signal/Noise Ratio
x10⁻²
x10⁻³
x10⁻⁴
x10⁻⁵
x10⁻⁶
x10⁻⁷
17
19
21
23

Figure 2-4



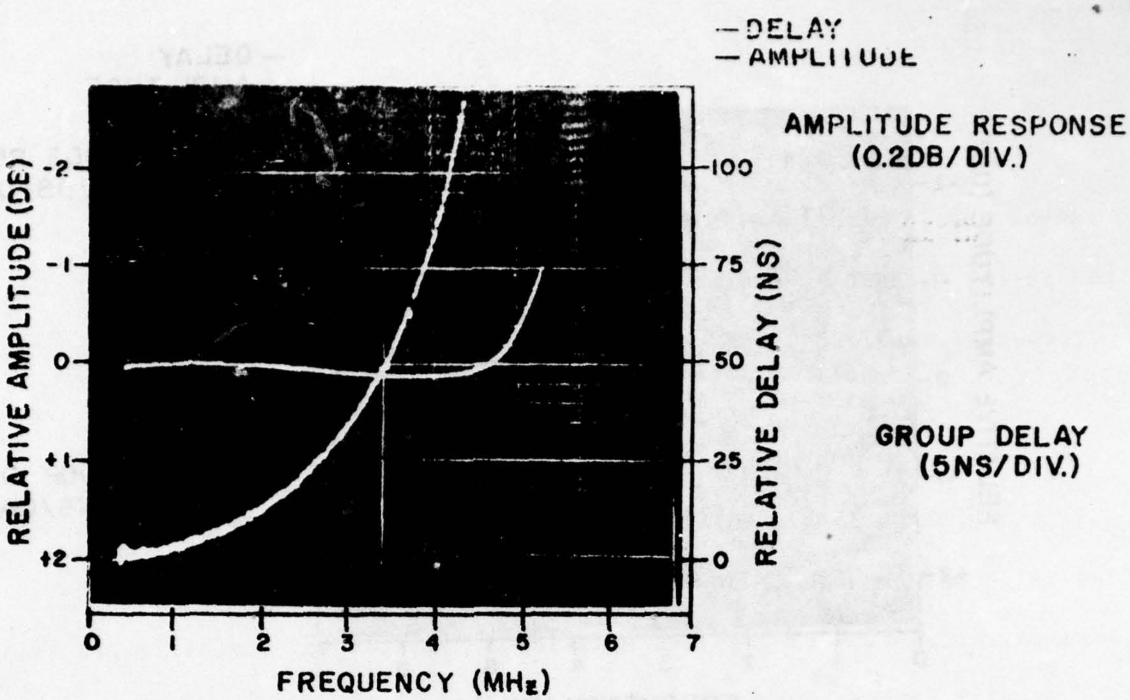
a) Filter Characteristics



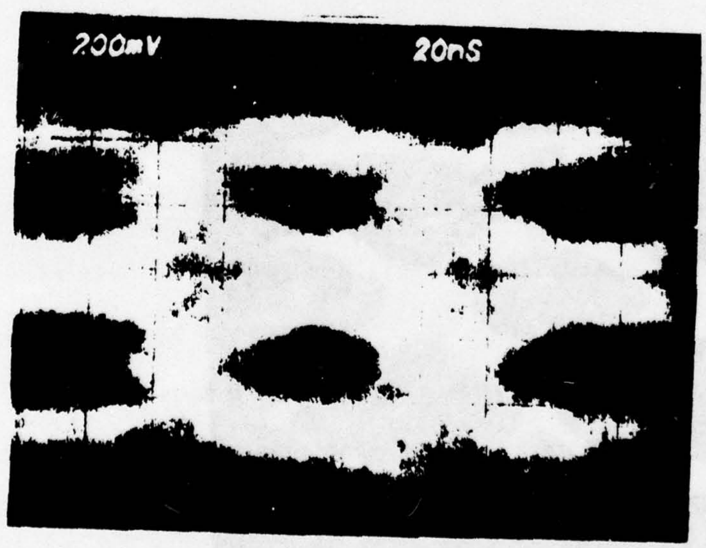
b) EYE PATTERN DISTORTION

Figure 2-5

6.9 MHz Notch Filter



a) Filter Characteristics



b) EYE PATTERN DISTORTION

Figure 2-6.

5.0 MHz Low Pass Filter

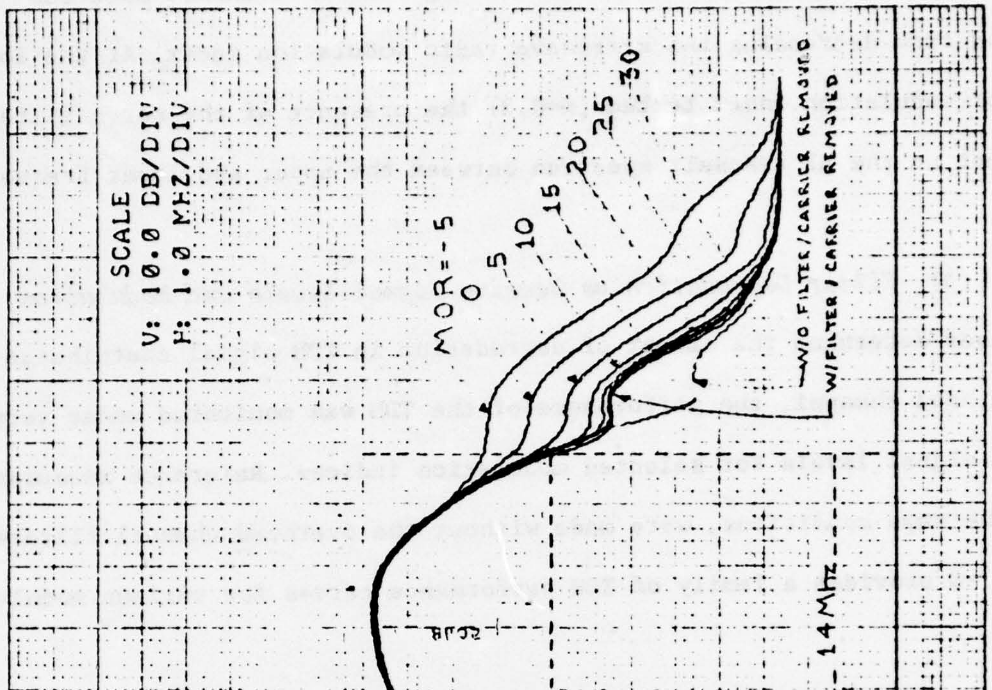

Transmit R-F spectrum for varying MOR using 6.9 Mhz notch filter and 6.9 MHz carrier
SCALE
V: 10.0 DB/DIV
H: 1.0 MHZ/DIV
MOR = -5
0
5
10
15
20
25
30
W/O FILTER/CARRIER REMOVED
W/FILTER/CARRIER REMOVED
1.4 MHz
6 DB

Figure 2-7

(b) The most significant changes in RF transmit spectrum resulted from decreasing the microwave radio modulation index. At the lowest value of modulation index tested (m=0.3) the presence of the notch filter had no effect on the RF transmit spectrum between the upper and lower frequency limits.

(3) *Filter Degradation vs Receive Signal Levels and Modulation Index.* To further determine the amount of degradation in TDM signal contributed by the overhead channel, the performance of the TDM was monitored under varying receive signal levels for selected modulation indices. Reference measurements, under the same conditions, were made without the overhead channel filters. Figure 2-8 provides a family of TDM performance curves for various modulation indices:

(a) Figure 2-8a shows the TDM performance without the overhead channel filter.

(b) Figure 2-8b shows the performance with a 7.5 MHz overhead channel filter.

(c) Comparing the two families of curves, at good receive signal levels (-48 dBm) and m=0.5 the incremental change in degradation due to the overhead channel is approximately 16%, the change for m=0.3 is 15%. At poor receive signal levels (-70 dBm), overhead channel degradation is 12% for a modulation index of 0.5 and only 1% for a modulation index of 0.3. However, absolute degradation, both with and without the overhead channel filters is greater for lower modulation indices.

(4) *Noise Measurements.*

(a) Noise measurements were made by first obtaining an X-Y

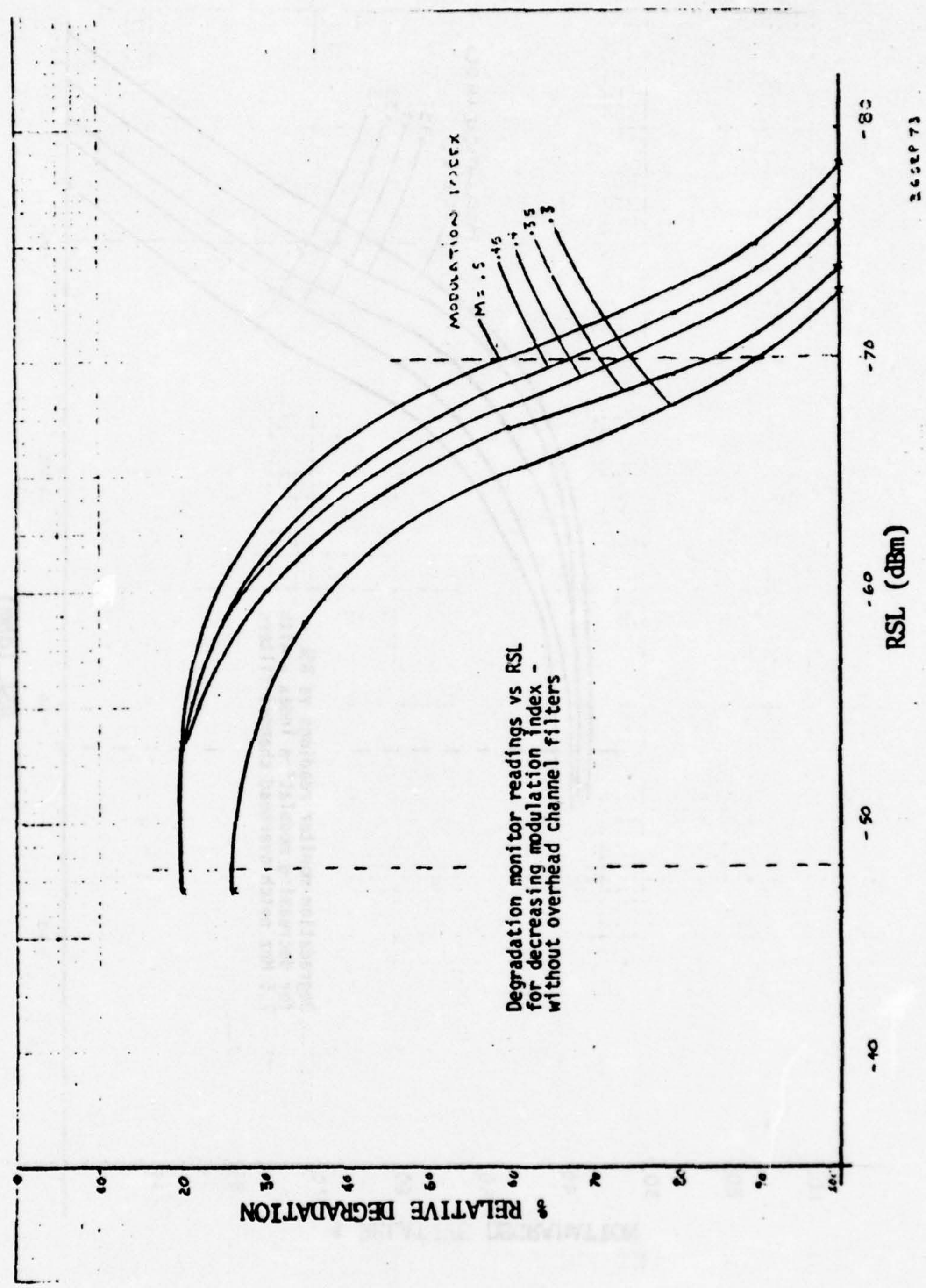

Degradation monitor readings vs RSL for decreasing modulation index - without overhead channel filters
RSL (dBm)
% RELATIVE DEGRADATION
MODULATION INDEX
M = .5
.45
.4
.35
.3
-40
-50
-60
-70
-80

Figure 2-8a

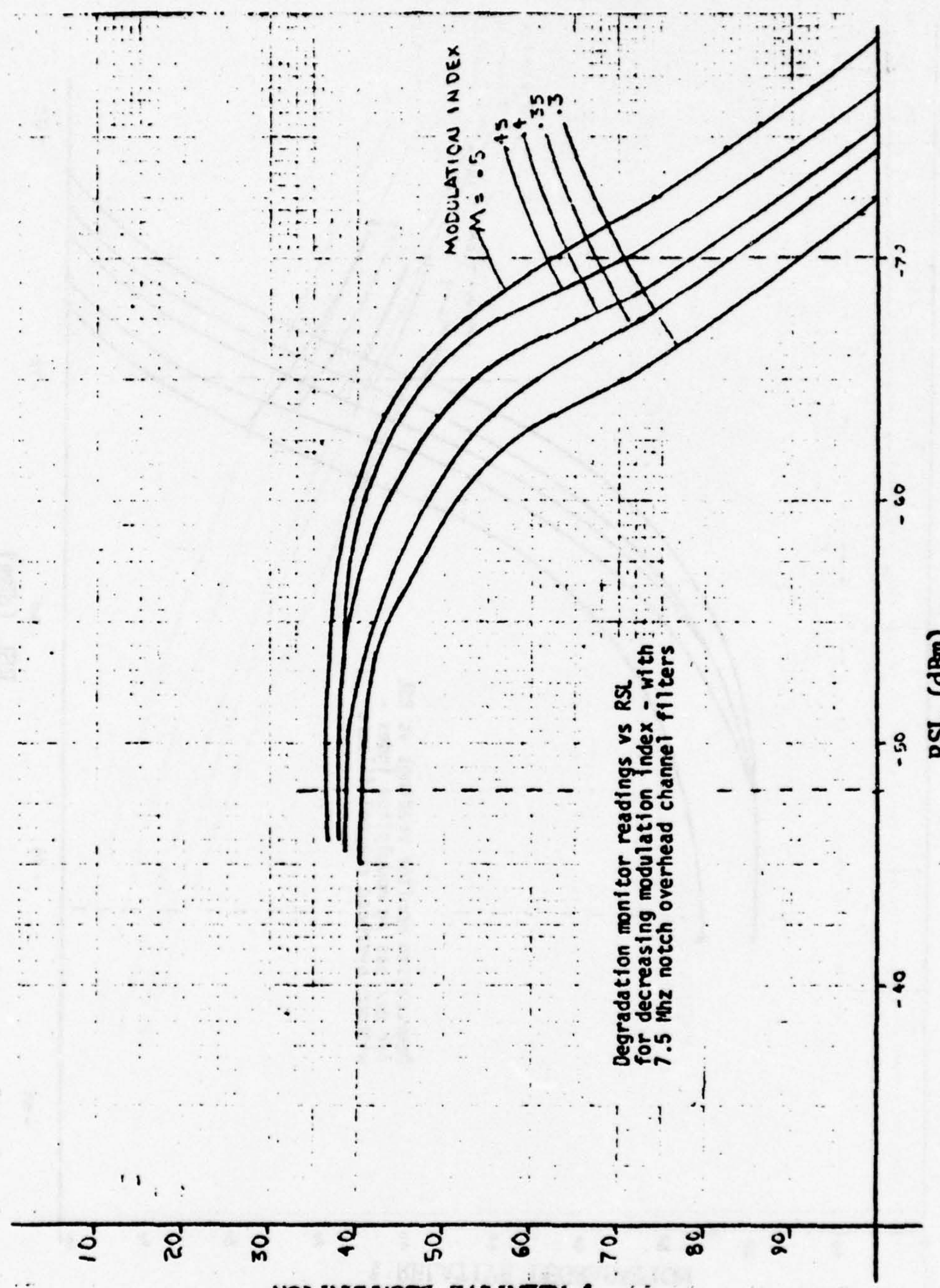

MODULATION INDEX
M = .5
.45
.4
.35
.3
Degradation monitor readings vs RSL for decreasing modulation index - with 7.5 Mhz notch channel filters
% RELATIVE DEGRADATION
10
20
30
40
50
60
70
80
90
-40
-50
-60
-70
RSL (dBm)

Figure 2-8b

plot of the RF transmit spectrum and measuring the depth of the notch created by the overhead channel filter. After radio link transmission, similar measurements were obtained from the receive RF spectrum. The difference between the two measurements represented the sum of the noise power developed in the overhead bandwidth resulting from the microwave radio intermodulation power which falls in the overhead channel position and the system's thermal noise power in the overhead channel bandwidth.

(b) To determine the carrier-to-noise ratio for each overhead channel test filter, power readings were recorded in a 200 KHz band around the carrier frequency, in 20 KHz increments. The MUX to overhead channel ratio was varied at the transmit site and the above readings were recorded at the receive site for each MUX to overhead channel ratio. In these tests the overhead channel carrier was unmodulated. Summation of results revealed:

1. Noise power in the overhead channel position of the received baseband spectrum was approximately 6 dB higher than in the transmitted baseband spectrum. The effects of MUX to overhead channel ratio on overhead channel C/N ratio are shown in Figure 2-9. The curve first shows that increasing MUX to overhead channel ratio decreases the C/N ratio in the overhead channel bandwidth.

2. Secondly, it shows that higher values of C/N ratio result from the use of low pass filters, which effectively reduce the transmit TDM spectrum and significantly reduce the out-of-band TDM signal which could be a contributor to intermodulation.

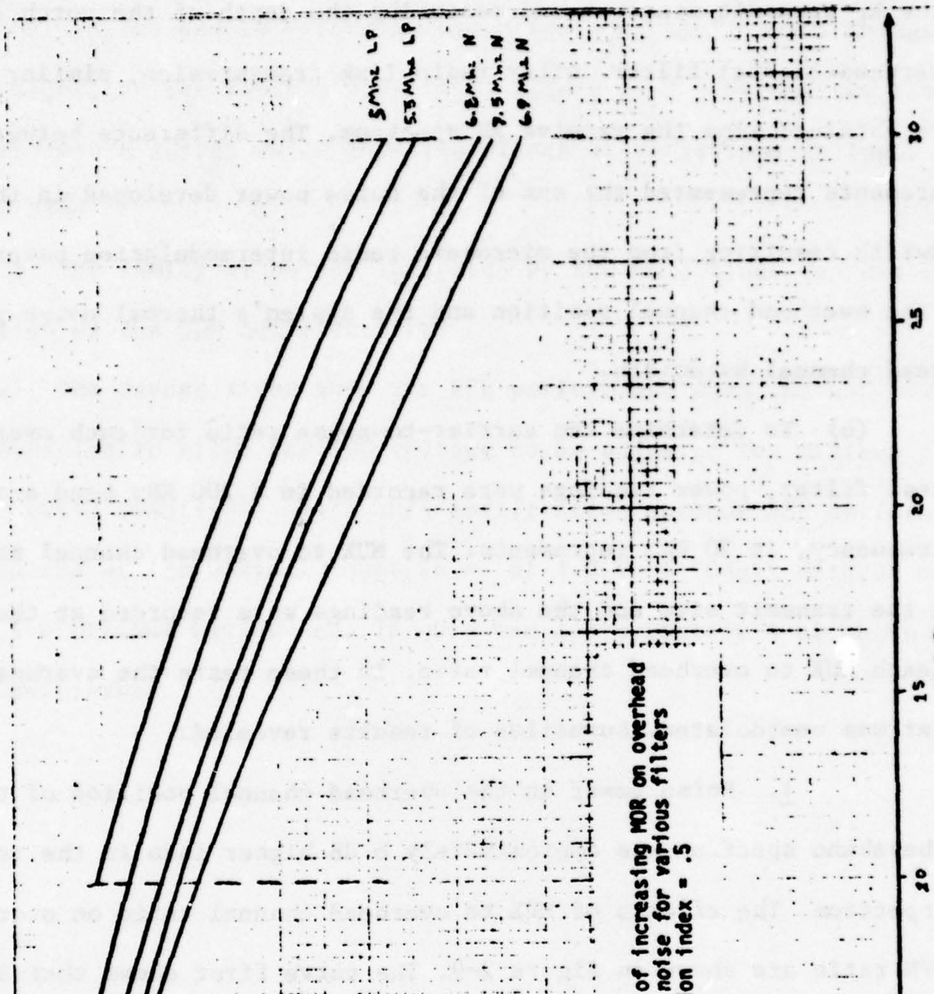

Effects of increasing MOR on overhead channel noise for various filters modulation index = .5
MOR
CARRIER + NOISE / NOISE (dB)
5 MHz LP
5.5 MHz LP
6.8 MHz N
7.5 MHz N
6.9 MHz N
5
10
15
20
25
30
30
40
50
60

Figure 2-9

2-4. **Effects of Signal Level Variations on TDM Performance.**

a. While conducting BER measurements on the TDM, it was observed that under high noise conditions and for a constant signal-to-noise ratio, the BER was a function of the TDM input signal level. At a S/N ratio of 20 dB, for example, input levels approximately 2 dB down from the specified 1.0 Vp-p resulted in a BER of $8X10^{-4}$, while increasing the input level to 4 dB above the nominal level resulted in a BER of $2.8X10^{-7}$.

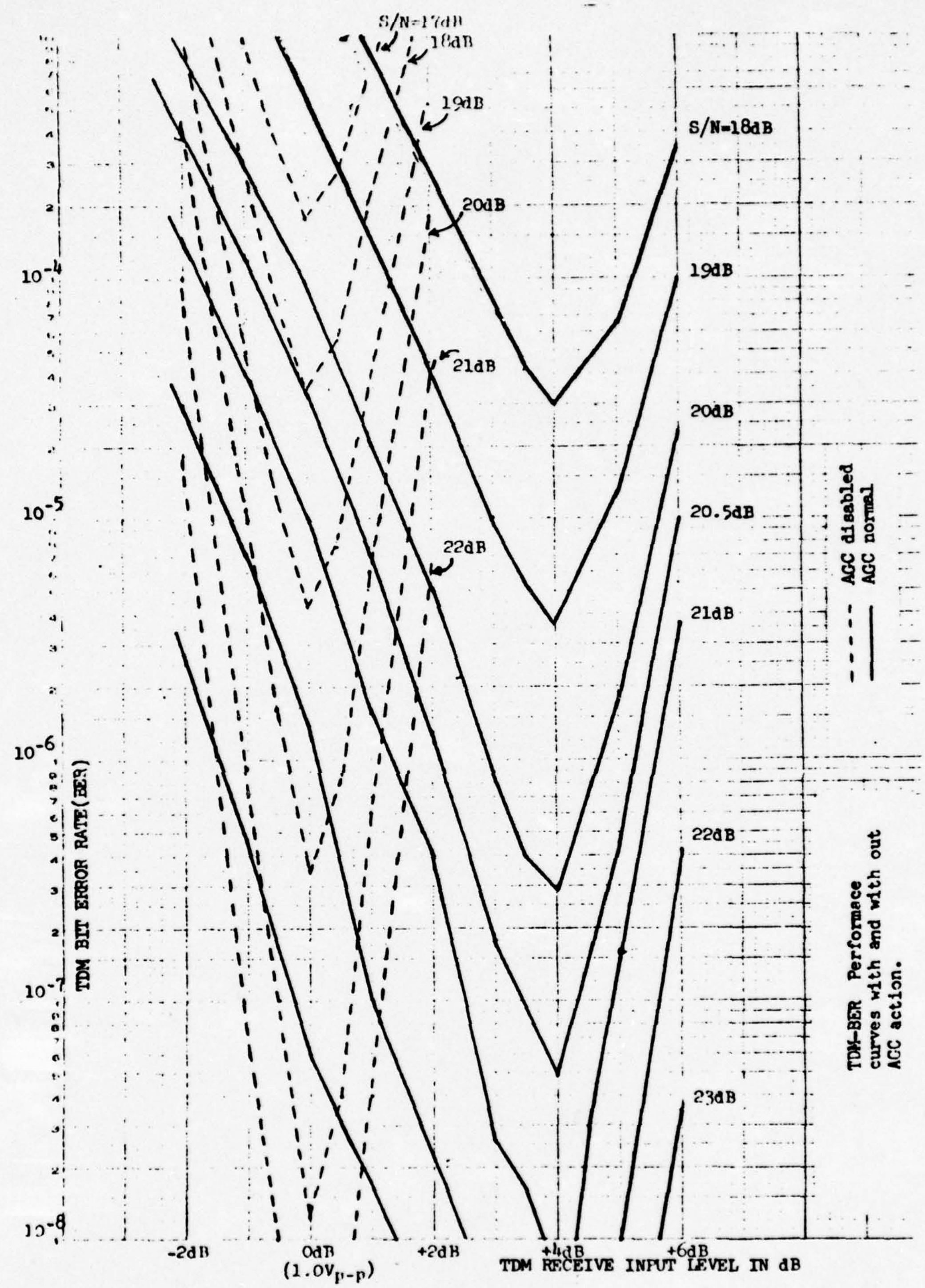
b. These observations led to the supposition that the TDM AGC circuitry, functioning as a peak-detector, maintains a constant voltage level to the comparator circuit of the multiplexer. Unable to discern signal from noise, this circuitry tracks the noise peaks and presents to the comparator circuits a composite eye pattern together with associated noise peaks. With respect to the received signal eye pattern, the slicing levels in the comparator circuits have been effectively increased. By increasing the input TDM voltage level, the noise peaks plus received signal are effectively amplified. The constant AGC output therefore represents a composite signal in which a significant portion of the noise peaks have been clipped. Accordingly the received eye pattern has been expanded and the relative slicing level more closely approaches the optimum level, thereby improving the TDM BER.

c. Tests were conducted to investigate the TDM performance under high noise conditions. Specific objectives were to determine the effects of TDM receive signal level variations on BER for various values of signal-to-noise

(peak-to-RMS) ratios and to determine the effects of small level changes in TDM input signal on the TDM AGC operation. Figure 2-10 provides two families of TDM performance curves which show the effect of variations in input level on the TDM BER:

(1) The family of curves indicated by the bold lines represents the normal design of the TDM AGC circuitry.

(2) The dashed lines show the BER performance when the AGC circuitry has been modified to allow the AGC voltage to be adjusted for minimum BER under high noise conditions. With this modification optimum BER performance can be obtained at the nominal input level of 1.0 Vp-p (0dB). Without modification, the optimum performance is obtained approximately 4 dB above the nominal input level.



S/N=17dB
18dB
19dB
20dB
21dB
22dB
S/N=18dB
19dB
20dB
20.5dB
21dB
22dB
23dB
AGC disabled
AGC normal
TDM-BER Performace curves with and with out AGC action.
TDM BIT ERROR RATE(BER)
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
-2dB
0dB
($1.0V_{p-p}$)
+2dB
+4dB
+6dB
TDM RECEIVE INPUT LEVEL IN dB

Figure 2-10

Chapter 3

SYSTEM PERFORMANCE MONITORING

3-1. Objectives. The objectives of system performance/degradation monitoring are threefold. These three objectives should be met in the following order with the most likely and critical problem areas addressed first, and less likely and less critical problem areas monitored as resources permit.

a. To inform technical controllers/maintenance personnel of an impending or actual transmission impairment.

b. To identify, to the greatest extent practical, the degraded equipment or location of the problem.

c. To give an indication of the probable cause of the problem.

3-2. Performance Monitoring.

a. An effective monitoring system depends on getting the monitor information to the operations/maintenance locations, logically combining the information in a way that meets the above objectives, and displaying the results in an easily interpreted manner. Good human engineering is, therefore, necessary to insure effective system performance monitoring and fault isolation. In

conjunction with the acquisition, telemetry, processing, and display of system performance assessment information, a well planned orderwire is also essential. The orderwire subsystem must include intersite maintenance channels, as well as system orderwire circuits for use by operations and maintenance personnel. The orderwire structure is also needed to coordinate operations and maintenance activities during system outages and trouble shooting. The combination of performance monitoring, telemetry data, and orderwire channels has been termed "system overhead" and is transmitted throughout the system by "overhead channels" as described in Attachment 3.

b. Since the performance monitoring system begins with the acquisition of system performance information, this is the first area to be addressed. There are two basic sources of performance assessment information from system equipment; warning/alarm detectors built into the equipment and "external" monitors (which may be partially or wholely contained in the equipment, or have been added as modifications). The internal monitor information output is generally in the form of a relay contact closure, indicator lamps, and/or meters, and is usually digital information. The warning and alarm lamp inputs and meter voltages are usually not brought out for telemetry purposes except, in some equipment, as a common alarm relay closure. Telemetry of common station alarms from radios, power supplies, TDMs, and terminal equipment could partially meet objectives 3-1a and b (informing personnel of trouble and pinpointing location) but generally do not offer much information concerning degradation (as opposed to service impairment or failure). The

existing alarms also do not give an indication of the problem cause (objective 3-1c) in most cases. As a first order of improvement to the above disadvantages of the existing alarms, other forms of monitors are now being considered for use in PCM/TDM systems. The levels in the system that were addressed first in the AFCS Digital Network Systems Facility investigations were the VF channel, radio/TDM interface (baseband), and the radio performance including the RF path.

(1) *VF Channel*. The first monitoring level to be considered here is the VF channel and its performance as a function of overall transmission system degradation. Naturally, as any portion of the system degrades to the point where errors begin to occur the effects of the errors will be seen at the VF channels. If the system perturbations are relatively remote from any terminals (for example, between two repeaters on a link) then the *only* indication at the terminals will be errors in the received data (and the results of these errors). For low error rates (10^{-5}) these errors will manifest themselves as impulse noise in the VF channels. For higher error rates the TDMs and/or terminals will lose frame occasionally and larger impulses, or signal dropouts, will occur (Attachment 2, VF Channel Assessment). Loss of frame is presently being detected in the D-2 terminal. This information can be brought out and analyzed for an indication of severe system degradation. Isolated errors in the T1 bit stream may be detected, on a statistical basis, by using the individual D-2 BF_t bits which are constantly being checked for errors. Since the BF_t bits occur at only 4000/second rate, the measurement of low levels of BER using the BF_t bits is a very time-consuming process. For example, to measure a BER of 10^{-6} to 10^{-7} at a 95% confidence level (assuming that the errors occur at the TDM level and, therefore, are subject to an error extension factor of 4)

would require examination of approximately 16 errors. These errors would occur in approximately $2.9X10^7$ BF_t bits and would require about 2 hours to accumulate. This does not, however, mean that 2 hours are required to become aware of problems on the system as they affect terminal performance and subscribers. By continuously computing the D-2 BER each time a new BF_t error occurs, a high error rate will be indicated as soon as the error rate estimator (ratio or errors to bits received) exceeds a specified amount (for example, $5X10^{-7}$) at a prescribed confidence level (for example, 95%). Thus the "waiting time" is inversely proportional to the severity of system degradation.

NOTE: By using the BER measurement and computation technique described above, the tolerance limits on the BER estimator decrease with an increasing number of errors (for a fixed confidence level and relatively steady-state system degradation) and the calculated BER becomes increasingly accurate.

(2) *TDM Level:*

(a) The next level of monitoring is at the high speed TDM. Because the TDMs interface the principal communication path where problems are likely to occur, that is the point where monitoring is most critical. For example, the collective TDM-to-TDM performance will usually determine the end-to-end performance of the terminals in a system. For the purposes of this portion of system monitoring, regenerative repeaters are considered as a TDM. TDM performance monitors include the phase-locked loop control voltage (AC and DC components), the three-level violation detector, and the waveform distortion degradation monitor.

(b) Proper use of these monitor points not only yield an indication of a problem; but in many cases, also give an indication of the probable cause of the problem.

(3) *Microwave Radio Level*. The microwave radios have several parameters which may be monitored continuously. One is the receive signal level which can give information relating to the path propagation and distant end transmitter output level. Receive signal level monitors have been installed and used on the digital transmission system for all radio link tests. By comparing the readings of receive signal level from two space diversity receivers a good indication of path, distant end transmitter, or receiver problems is available. A second monitor parameter being considered for use with the radios is the amplitude modulation (AM) present on the received IF signal prior to limiting. If the transmitted signal is nearly AM-free (as it should be), then the amount of AM present on the receive IF signal should increase as multipath and receiver noise increases, or frequency and phase response deteriorates. Thus, the AM components could show problems in a receiver, path, or transmitter on a microwave link. This technique will be investigated further subsequent to this report. Other parameters on the microwave radios which can be monitored are transmitter output, frequency source phase lock, and baseband notch noise (6 September 1973 Test Report).

3-3. <u>Performance Monitor Equipment</u>. Considerable experience at the AFCS Digital Network Systems Facility has shown that the principal determining factors of end-to-end system performance are the microwave radio links (transmission channel). Therefore, it is towards this portion of the installed

system that most of the performance monitors have been oriented. Figure A5-1 of Attachment 5 shows a block diagram of the system performance monitoring and data acquisition configuration for the "TDM - transmission channel - TDM" portion of the PCM/TDM system. The parameters that are continuously measured and recorded are receive signal level, TDM phase-lock loop (12.5526 MHZ receive clock) control voltage, TDM automatic gain control voltage or calibration signal level, TDM three-level violation (error) density, waveform distortion monitor output, and 12.5526 Mbps bit error rate. In addition, the overhead channel idle channel noise is recorded during link tests. A complete discussion of the performance monitor equipment and the associated calibration curves are given in Attachment 5. The data associated with system performance tests is given in the chapter of this report which covers the specific area of measurements (for example, VF channel tests and overhead channel tests).

Chapter 4

SYSTEM MAINTENANCE PROPOSAL

4-1. Introduction.

a. The proposed maintenance concept which follows represents a first step in the continuing development of a detailed maintenance concept for a PCM/TDM microwave transmission system. Additions and alterations will have to be made as more detailed information becomes available, or if the concept needs to be molded to fit special situations or constraints.

b. The primary goals of the proposed maintenance concept are to insure that the maintenance philosophy and resultant actions reflect a systems approach, and to realize a reduction in the number of personnel by consolidating maintenance units. The following summary of the proposal establishes how these goals will be attained.

c. In order to achieve a systems approach to maintenance, provisions will be made to monitor parameters which are indicative of the operation of the system. Also, personnel will have a basic knowledge of the theory of operation of the system as a whole, as well as individual equipment items. In order to allow the consolidation of maintenance units, there will be devices which allow important system parameters to be remotely monitored, and allow remote fault isolation to the site level, and to major equipment units

within the site. The need for preventive maintenance will be held to a minimum by employing fault prediction methods and by using equipment which is inherently stable. The fact that maintenance personnel will not be at every site will introduce the need for redundancy for each type of equipment at a site. This redundancy must be capable of immediately assuming operation of the system when the primary equipment fails. The ability to switch to the redundant unit will allow maintenance personnel time to travel from the maintenance unit to the site.

d. The following is a list of some of the specific requirements of the proposal; however, it should be emphasized that these requirements are subject to change depending on the exact configuration of the equipment.

(1) The mean time required to perform onsite repairs must not exceed one hour.

(2) The travel time (one-way) from the maintenance unit to the site will not exceed three hours.

(3) A site that has a possibility of being isolated from a remote maintenance unit for seven days or more will be manned by maintenance personnel.

(4) The MTBF of individual items of equipment (for example - one TDM unit) should be at least five months.

4-2. Objectives.

a. The first objective of this maintenance concept is to insure that the

PCM/TDM microwave transmission system will have a low probability of system failure due to inherent defects in the maintenance system.

b. The second objective is to keep the life cycle cost of the system as low as possible.

4-3. Summary. The maintenance concept may be summarized as follows:

a. Maintenance personnel at the organization level will be assigned to a central maintenance work center. This unit will have maintenance responsibility for as many sites as are economically or physically possible. Onsite maintenance will consist of isolation and replacement of line replaceable units (LRU) and/or system alignments and adjustments. All other maintenance will be performed offsite. System parameters that predict system failure will be utilized to reduce the requirement for preventive maintenance.

b. The following documents also form a part of this maintenance concept:

(1) MIL STD 454C	(5) MIL STD 471
(2) MIL STD 1250	(6) MIL STD 781B
(3) MIL STD 882	(7) MIL STD 757
(4) MIL STD 1472A	(8) MIL STD 721B
	(9) MIL STD 280A

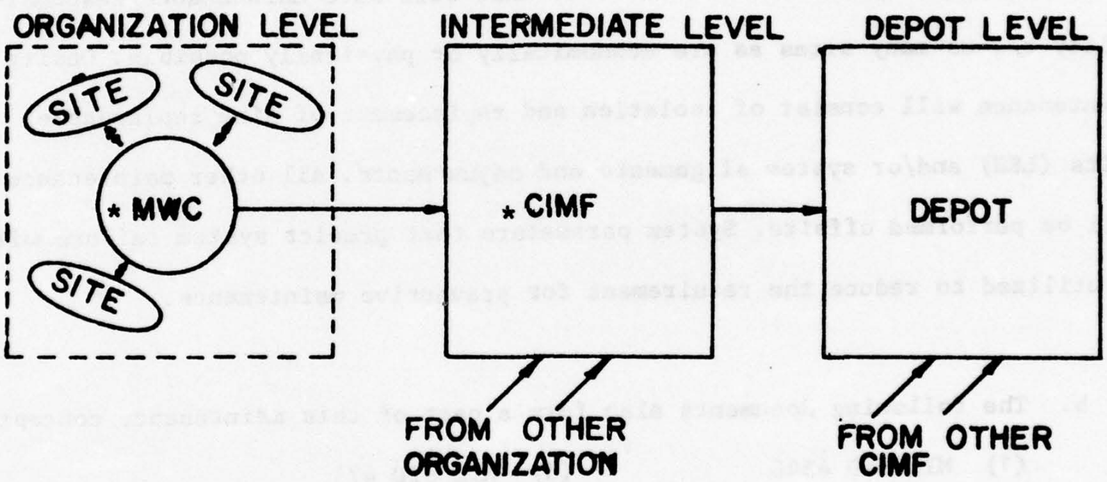
4-4. Maintenance Organization. The responsibilities, levels of maintenance, and maintenance practices of the maintenance organization will be divided into three levels; organization, intermediate, and depot level (see Figures 4-1 and 4-2):

a. Responsibilities:

(1) *Organization*. Maintenance will be the responsibility of a centralized maintenance work center. The maintenance work center will be directly responsible for the maintenance of one or more sites.

(2) *Intermediate*. Maintenance on noncryptographic equipment will be the responsibility of the appropriate central intermediate maintenance facility, but intermediate level maintenance on cryptographic equipment will be the responsibility of the maintenance work center.

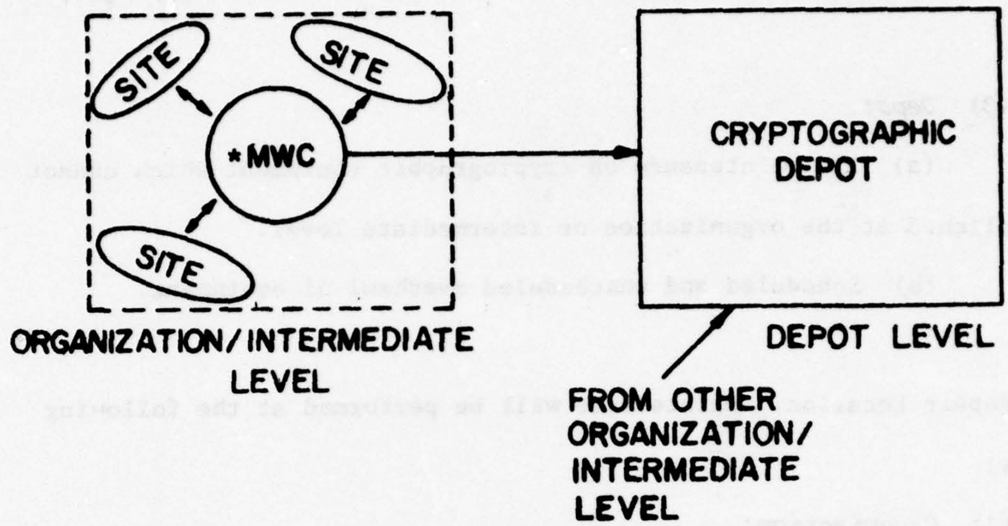
(3) *Depot*. Maintenance will be the responsibility of the depot appropriate for that type of equipment.



*MWC - Maintenance Work Center
*CIMF - Central Intermediate Maintenance Facility

Maintenance Organization for Noncryptographic Equipment

Figure 4-1



*MWC - Maintenance Work Center

Maintenance Organization for Cryptographic Equipment

Figure 4-2

b. Levels of Maintenance. Maintenance to be performed will consist of:

(1) *Organization:*

(a) Complete equipment exchange of cryptographic equipment.

(b) System alignments and adjustments.

(c) Faulty line replaceable units (LRUs) will be isolated and replaced.

(d) Minor repairs on LRUs such as cleaning contacts, replacing connectors, etc.

(e) Preventive maintenance of systems, subsystems, and LRUs.

(2) *Intermediate:*

(a) Replacing defective lamps, fuses, and pluggable subassemblies

on cryptographic equipment (will be performed at the maintenance work center).

(b) Isolating and replacing faulty parts in noncryptographic LRUs.

(3) *Depot:*

(a) All maintenance on cryptographic equipment which cannot be accomplished at the organization or intermediate level.

(b) Scheduled and unscheduled overhaul of equipment.

c. Repair Location. Maintenance will be performed at the following locations:

(1) *Organization:*

(a) Onsite:

1. System alignments.

2. Faulty LRUs will be isolated and replaced.

3. Cryptographic equipment will be exchanged.

4. System and subsystem preventative maintenance inspections will be performed.

(b) Maintenance Work Center (if the maintenance work center is responsible for only one site, they may be collocated):

1. Preventive maintenance on LRUs.

2. *Minor* repairs on LRUs.

(2) *Intermediate:*

(a) Maintenance of noncryptographic equipment will be performed at the appropriate central intermediate maintenance facility.

(b) Maintenance of cryptographic equipment will be performed at the maintenance work center.

(3) *Depot.* Depot level maintenance will be performed at the depot which has responsibility for that type of equipment.

c. Maintenance Practices. Primary emphasis of maintenance at the various levels will consist of the following:

(1) *Organization:*

(a) Maintaining the system within required system tolerance limits.

(b) Minimizing preventive maintenance by performing preventive maintenance *only* on those items which cause no measureable downward trend in system performance prior to system failure which cannot be prevented by redundancy. Maintenance personnel will not be assigned to a site solely for the purpose of performing cryptographic equipment key changes.

(2) *Intermediate.* Maintenance required to return LRUs to full operational capability.

(3) *Depot.* Only programmed overhauling of those items which cause no measureable downward trend in system performance parameters prior to a system failure which cannot be restored by redundancy.

4-5. <u>Time Change Requirements</u>. Those items which have a limited life expectancy will be identified. If the limited life expectancy item has a redundant unit, then the item will not be changed until it fails. If the limited life expectancy item has no backup, and its failure will result in

a system failure, then it will be changed after an interval not to exceed the life expectancy.

4-6. Degradation Diagnostic Techniques:

a. The personnel at the technical control facility (TCF) will notify the maintenance work center personnel of the need for maintenance if any of the following occurs:

(1) Total system failure.

(2) Degradation of the operational capability of the system.

(3) System parameters exhibit a continuing downward trend.

(4) Equipment switches to the backup unit.

b. The TCF personnel will forward data obtained from remote monitors. This data will be used by the maintenance work center personnel to isolate faults to the specific major equipment unit at a site. Any further fault isolation will be carried out onsite. Maintenance work center personnel will also analyze LPA and other performance indicators to determine areas where degradation is occurring so that corrective action can be taken.

4-7. Calibration. Built in test equipment (BITE) will be calibrated onsite by maintenance work center personnel using maintenance work center test equipment. Calibration of the maintenance work center test equipment will be accomplished by traveling PMELs.

4-8. <u>Corrosion Control</u>. Corrosion control methods that meet the requirements of MIL STD 1250 and MIL STD 454C will be used throughout the system.

4-9. <u>Maintenance Manning</u>. Requirements are as follows:

a. Organization Level:

(1) Any person assigned to the maintenance work center will have the necessary skill and knowledge to fill any personnel position (except the supervisor's position) with a minimum requirement for OJT.

(2) In order to reduce maintenance personnel requirements, the maintenance work center should be responsible for as many sites as physically and economically possible (Attachment 6).

(3) Maintenance personnel will be available at the central maintenance unit at least seven days per week and eight hours per day.

(4) Maintenance personnel at the maintenance work center will all be radio relay repairmen (Attachment 6).

(5) The number of personnel assigned to each maintenance work center will be dependent on the circumstances for that particular maintenance work center.

b. Intermediate Level. Central intermediate maintenance facility personnel will be radio relay repairmen.

c. Depot Level:

(1) Radio relay repairmen will perform maintenance on noncryptographic equipment at the depot level.

(2) There will be no change required in the AFSCs of personnel at the cryptographic depot.

4-10. System Safety. A system safety program that complies with MIL STD 882 will be established, and the system will meet the safety requirements of MIL STD 882, MIL STD 1472A and MIL STD 454C.

4-11. Storage. Storage requirements at the various levels are as follows:

a. Organization:

(1) The maintenance work center must have storage facilities capable of containing all necessary spare items.

(2) The spare LRUs will be packed in a kit form so they may be easily transported from the maintenance work center to the site.

(3) Spares will not be stored onsite unless they are used on a regular basis and are too bulky and/or fragile to be carried in kit form.

(4) The number of spares stored must be large enough that there is an acceptable low risk of a system outage occurring due to lack of spares. This number will be specified when the equipment has been specified.

(5) All items must be capable of withstanding the shock and stress associated with being transported from the maintenance work center to the site without requiring excessively expensive protective containers.

b. Intermediate:

(1) The central intermediate maintenance facility will have storage facilities for all the spare items necessary to repair faulty noncryptographic equipment.

(2) The maintenance work center will have storage facilities for the spare items necessary to perform intermediate level maintenance on cryptographic equipment.

c. Depot. Depots will have storage facilities for the spare items necessary to repair the equipment which is the responsibility of the depot.

4-12. Ground Support Operations. Vehicles will be provided to transport maintenance personnel and equipment from the maintenance work center to the site. These vehicles should be capable of carrying two people and several hundred pounds of prepackaged spares and test equipment. Personnel and equipment must be protected from environmental hazards. Depending on the location, vehicles may be required to operate on unimproved roads, and may have to be four-wheel drive.

4-13. Aerospace Ground Equipment (AGE):

a. The AGE that is transported from the maintenance work center to the site will be packed in protective containers. In order to prevent system outages due to failure or lack of AGE, the maintenance work center should either have spare AGE or AGE should be available within 24 hours. This spare AGE will

consist only of those items absolutely necessary to return the system to minimum operational standards.

b. Highly specialized or nonstandard AGE will not be used if government furnished AGE is available that will satisfy requirements. All AGE will meet the requirements of MIL STD 454C. In addition, if the total cost of buying and maintaining built in test equipment (BITE) is less than the cost of buying and maintaining nonBITE, the BITE will be used, and if BITE is required to meet maintainability time limits, the BITE will be used (paragraph 4-15, Maintainability).

4-14. Technical Data:

a. Every level of maintenance will have technical data containing the following information:

(1) The theory of operation in sufficient scope to allow personnel to perform maintenance appropriate at their level.

(2) Common fault isolation procedures of the appropriate level.

(3) PMIs applicable to that level of maintenance.

(4) An explanation of the AGE at that level of maintenance.

b. In addition, the technical data at the organization will contain the following information:

(1) An explanation of how to calibrate BITE using maintenance work center test equipment.

(2) Block diagrams of the system with indications of required system parameters at test points.

(3) An explanation of how the maintenance work center personnel may isolate faults of major equipment units using the information forwarded by the technical control facility (TCF).

(4) Timing diagrams for digital circuits.

4-15. Maintainability.

a. The following time requirements must be met to achieve a maintainable system:

(1) Maintenance work centers will be located so that they are not more than three hours travel time (one way) to any site for which they are responsible.

(2) The mean maintenance time onsite will not exceed one hour.

(3) Maintenance personnel will be stationed at any site which is inaccessible for periods longer than one week.

b. The equipment design features required are as follows:

(1) All equipment will meet the requirements of MIL STD 454C.

(2) Remote and/or local alarm devices will be designed to alarm whenever key or critical parameters fall below established minimum threshold standards.

(3) A maintenance coordination circuit, to provide necessary communications for maintenance personnel, will be incorporated into the system.

(4) The tolerances of components will be small enough that aging will not degrade system performance significantly during the life expectancy of the item.

(5) The human engineering and environmental requirements of MIL STD 1472A, and MIL STD 454C will be met by all equipment in the system and all equipment required to maintain the system.

(6) The system must be capable of being maintained within specifications by a radio relay repairman, with skill level five experience, using only furnished AGE, spares, technical data, and BITE.

c. A maintainability demonstration will be carried out IAW MIL STD 471.

4-16. Reliability.

a. The following time requirements must be met to achieve a reliable system:

(1) Uninterrupted power systems should have a mean time between failure (MTBF) of two years.

(2) MTBF goals for other equipment items have not been fixed at this time; however they will have to approach the predicted values as noted in Attachment 6.

b. The equipment design features required are as follows:

(1) Uninterrupted power systems should be installed at each site in order to gain independence from commercial power sources.

(2) Whenever possible, redundant units will be switched automatically.

(3) A reliability demonstration will be carried out IAW MIL STD 781B and MIL STD 757.

Chapter 5

CONCLUSIONS

5-1. Introduction. The conclusions presented below are derived from the test results in Attachments 2 through 4 and the investigative work performed in the AFCS Digital Network Systems Facility. *Recommendations*, where pertinent, are also listed.

a. VF Channel Assessment.

(1) *Common Measuring Technique*. A common measuring technique is available whereby an approximate determination of the quality of a static PCM VF channel can be made. However, because the measured analog signal is derived from phase distortion of a test tone, the resulting indication will not necessarily reflect amplitude distortion. Further investigation of this technique will be conducted before it can be considered a fully effective VF channel test.

(2) *In-Service/Out-of-Service Tests*. As an in-service test, monitoring the occurance of D-2 frame errors provides a satisfactory indication of T1 BER at rates less than 10^{-7}. An estimation of T1 BER can also be obtained by recording the impulse noise on an unused VF channel. However, neither technique is predictive. Considerable degradation must occur prior to the onset of bit errors which generate impulse noise in the VF channel or D-2 frame errors. Once bit errors occur, the resulting VF channel impulse noise levels are distributed throughout the amplitude range, and changes as small

as 1 dB in the baseband S/N ratio result in changes in BER of approximately an order of magnitude. In FDM systems impulse noise counts and amplitude levels start at low values and increase in proportion to increasing degradation. Either measuring technique, however, may be applied successfully in a fault isolation process which compares impulse noise counts and/or D-2 frame errors with T1 BER and the S/N ratio input to the eight-port TDM.

b. Overhead Channel Investigation:

(1) *Filter Characteristics.* Low pass filters, with envelope delay and frequency response characteristics similar to Figure 2-6a, severely degrade the TDM signal. Notch filter insertion of an overhead channel is technically feasible, and notch filters designed to provide delay equalization produce minimum distortion to the TDM signal. The characteristics of such a filter are displayed in Figure 2-5a.

(2) *Bandwidth Occupancy.* Notch filters with characteristics similar to the 6.9 MHz shown in Figure 2-5a provide an acceptable range of MUX to overhead channel ratio in which the composite RF transmit spectrum is contained within the 14 MHz band limits. Lowering the microwave radio modulation index also improves transmit bandwidth but at the expense of increased degradation to the TDM signal.

(3) *Noise Measurements.* System thermal noise and radio (MR-300) intermodulation power in the overhead channel filter position of the received baseband spectrum averaged approximately 6 dB higher than in the transmitted baseband spectrum.

(4) *Recommendation*. With respect to efficient O&M, it is generally desired that orderwire channels which have the capability to "drop and insert" status and control information be provided at unmanned repeaters. In addition, although not presently provided in most orderwire structures, the orderwire channel should be available in the event of path failure. With the orderwire technique tested, drop and insert is difficult to achieve unless baseband access is provided. In addition, this technique reduces system flexibility, impacting significantly IF repeater configurations and the use of digital radios. Because the overhead channel is inserted in the radio baseband, the orderwire is not available if the path fails or severely degrades. Because of these limitations, alternative techniques will be evaluated to include different insertion techniques, AM or FM of RF carrier, digital overhead channels, and independent UHF/VHF subsystems.

c. TDM Performance vs Variations in Signal Level:

(1) *Performance Characteristics*. Under high noise conditions, the eight-port TDM (VICOM 4000 series) BER performance is not ideal and can be improved by three orders of magnitude by disabling the AGE control voltage, and holding the three level waveform input level constant at 1.0 volt$_{p-p}$ (Attachment 4).

(2) *Recommendation*. Consideration should be given to the specifications of the TDM AGC circuitry so as to optimize BER performance under high noise conditions. This could probably be done by changing the existing AGC peak detector to an averaging detector.

d. System Performance Assessment.

(1) *TDM Level*. Because the high speed TDM (8-port) interfaces the principal communications path where problems are likely to occur, this is the point where monitoring is most critical. Additionally, the TDM-to-TDM performance will usually determine the end-to-end performance of the communications link. Proper use of the TDM monitor points provides an indication of system degradation and, in many cases, the probable cause. The principal TDM performance indicators include:

(a) Degradation monitor.

(b) Three-level error density.

(c) TDM reframe rate.

(d) TDM phase locked loop control voltage.

(2) *Microwave Radio*.

(a) Microwave radios have several parameters which may be monitored continuously. These indicators include:

1. Transmitter output.

2. IF frequency (automatic frequency control correction).

3. Phase locked loop voltages (frequency sources).

4. Out-of-band noise (IF and baseband).

(b) In addition, receive signal level provides information relative to transmission path and distant end transmitter output.

(3) *Recommendations*. The existing equipment performance indicators provide a partial digital indication of system performance and, in some cases, information to aid in the location of a problem. Additional analog type monitors

that yield information on equipment/system degradation are needed to *predict* service impairment and permit maintenance action prior to an actual outage.

(a) Because of the numerous analog quantities that should be monitored a programmable scanning digital voltmeter could be used as a means of acquiring the desired data.

(b) A sequential/addressable polling type telemetry technique would be a reliable way of getting the monitored and processed data to manned concentration points and maintenance centers.

(c) The logical combination of data should be accomplished through programmed computer control or special programmed equipment.

(d) Status display should be computer CRT display or visual annunciator display designed for the specific application.

DESCRIPTION OF TEST FACILITY

1-1. Geographical Description:

a. The test facility at HQ AFCS, Richards-Gebaur AFB, MO is composed of three microwave sites geographically configured in a triangular link as shown in Figure A1-1. Two of the sites, Bldgs 1202 and 1700, contain identical PCM/TDM terminal equipment interconnected through common station equipment, patch bays and distribution frames typical of the Defense Communications System (DCS). These terminals also have audio, digital, and video patching facilities, overhead channel equipment, and two space diversity microwave radio sets. The third site, Bldg 1104, can be configured as either a baseband, regenerative, or IF repeater. In addition to two space diversity microwave radios, the repeater site also contains a digital and video patch facility, and overhead channel equipment.

b. In addition to the PCM/TDM transmission equipment, the test facility also has a parallel FDM/FM frequency diversity, microwave link between Bldgs 1202 and 1700.

1-2. Major Equipment Description:

a. Exclusive of the standard audio and digital patch facilities, both terminal sites contain two TSEC/CY-104s and a VICOM eight port and four

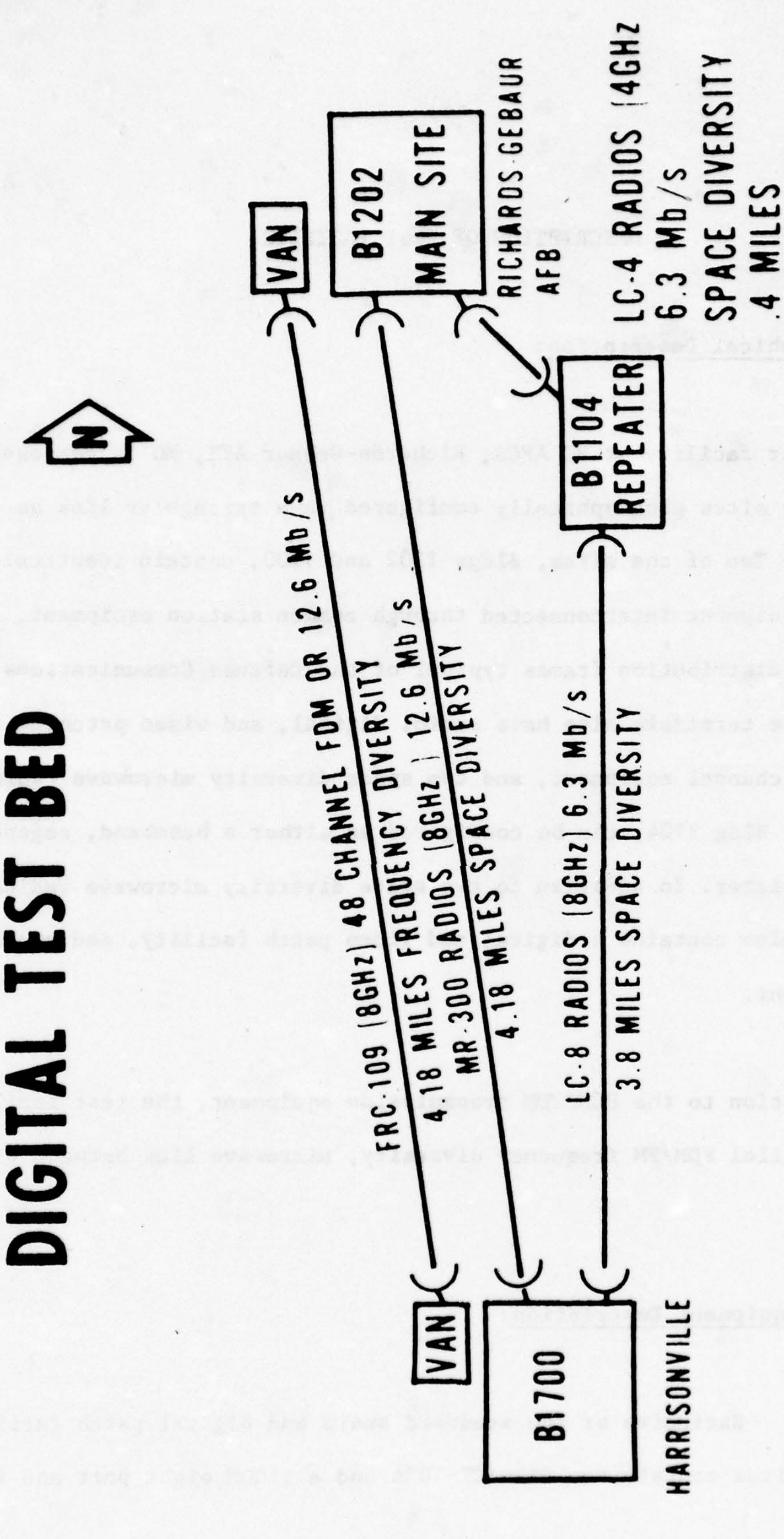

DIGITAL TEST BED
N
VAN
B1202
MAIN SITE
RICHARDS-GEBAUR AFB
LC-4 RADIOS (4GHz)
6.3 Mb/s
SPACE DIVERSITY
4 MILES
B1104
REPEATER
FRC-109 (8GHz) 48 CHANNEL FDM OR 12.6 Mb/s
4.18 MILES FREQUENCY DIVERSITY
MR-300 RADIOS (8GHz) 12.6 Mb/s
4.18 MILES SPACE DIVERSITY
LC-8 RADIOS (8GHz) 6.3 Mb/s
3.8 MILES SPACE DIVERSITY
VAN
B1700
HARRISONVILLE

Figure A1-1

port high speed TDM. The microwave link between these terminals is provided by the Motorola MR-300, a baseband direct modulation radio. The link between Bldg 1202 and the repeater is via a Philco-Ford LC-4D, IF heterodyning radio, while the link between Bldg 1700 and the repeater is provided by a Philco-Ford LC-8D, also an IF heterodyning radio. Intersite communications is provided by an overhead channel. The overhead channel equipment consists of a Farinon LD-3, four-channel FDM and a Lenkurt 54A FM modem.

b. The repeater site, Bldg 1104, is configured as an unmanned repeater with expanded test and patch facilities. Two four port VICOM TDMs are provided at this location as a means of data regeneration testing. The Philco LC-4D and LC-8D microwave radio complete the links between the repeater and the terminal sites. Identical overhead channel equipment is also used.

1-3. <u>System Signal Flow</u>. The normal PCM/TDM VF channel input-to-VF channel output is illustrated in Figure A1-2 and described below:

a. The incoming VF channels originate at the Ø dBm equal level patch board (point A). The input signals are then attenuated by 16 dB pads before being applied to the -16 dBm VF channel inputs of the CY-104. The CY-104 provides time division multiplexing, analog-to-digital conversion, signal conditioning, and bulk encryption of 24 VF channels. The D2 channel bank, HY-12, provides the interface between the VF channel and the PCM signal processing.

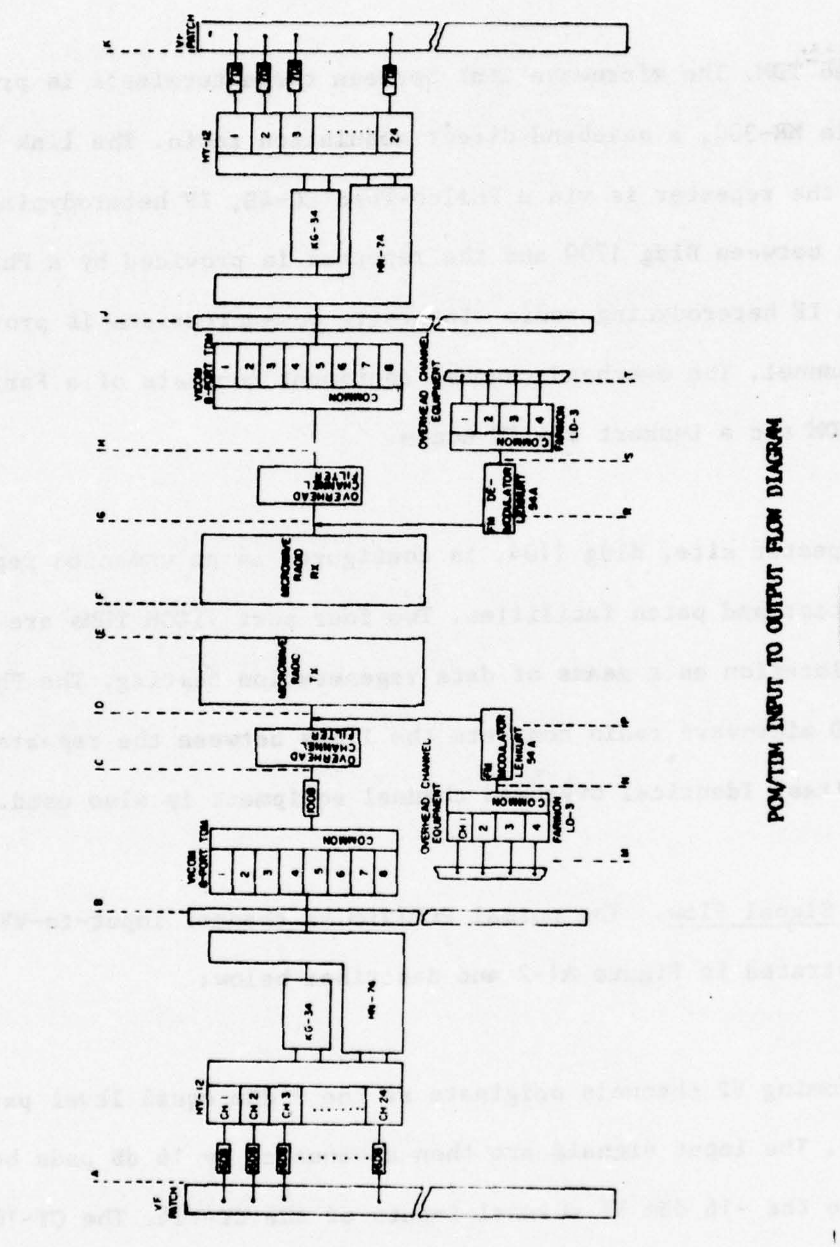


Figure A1-2

The incoming VF signals are first band-limited to 3.4 KHz and then sampled at an 8000 sample-per-second rate. The sampled analog signal levels of the 24 VF channels are then time division multiplexed into a single pulse amplitude modulated (PAM) data stream. Each sample is next quantized into one of 256 discrete steps by coding it into an 8-bit word. The additional 8000 framing bits per second results in the digital output rate of 1.544 Mbps - the standard T1 rate (24X8000X8+8000 = 1.54Mbps).

b. Signalling and idle/busy status of each channel is conveyed to the receive terminal using the least significant bit of each sixth 8-bit word for that channel. Several major and minor alarm functions, as well as local and distant-end terminal status information are also made available and transmitted to the opposite end for alarm/status reporting purposes.

c. The 1.544 Mbps output data stream is conditioned by an interface circuit external to the channel bank and then encrypted by the KG-34. The KG-34 output is then coded into 50% bipolar signal by the HN-74 for transmission to a high speed TDM. The encrypted T1 input is transmitted to the high speed TDM via ordinary twisted pair wire through the digital patch bay (point B).

d. The TDMs used in the test facility are VICOM 4 and 8-port units which bit interleave four or eight independent T1 data streams and TDM overhead bits

into a 6.2763 Mbps or 12.5526 Mbps output data stream. The resulting binary signal is applied to a partial response filter in the TDM which reduces the frequency spectrum to one-half that required to transmit a unipolar NRZ data stream. The resulting output is a three-level partial response waveform (point C). This signal is subsequently transmitted to a video patch board via 75 ohm coaxial cable.

e. Orderwire and telemetry is provided by a Lenkurt 54A program channel modem and a Farinon LD-3 four channel frequency division multiplexer. (Refer to points M, N, and P). The Lenkurt 54A transmit filter units provide a 30 dB notch in the TDM transmit spectrum at 7.5 MHz. The overhead channel carrier is frequency modulated by the LD-3 output which occupies a bandwidth from 4 to 20 KHz. The 7.5 MHz FM carrier is inserted in the notch in the TDM transmit spectrum. An attenuator is used at the input to the transmit filter unit to establish the optimum TDM to overhead channel power ratio. The optimum MUX to overhead channel ratio is based on achieving good orderwire channel performance (for example, low noise) while maintaining satisfactory RF bandwidth.

f. After combining the TDM and overhead channel signals, the resulting composite signal is applied to the microwave radio baseband (point P). In the radio, the signal is divided and applied to two separate transmitters, providing space diversity transmission. For link testing a waveguide attenuator has

been inserted at the output of each transmitter. This attenuator is used to "simulate" a longer path by decreasing the distant end receiver signal level.

g. Attenuation at the transmit end is necessary because the links are operated in a space diversity configuration - two independent antennas and receivers whose output is combined to produce the radio baseband output.

h. After FM demodulation (point G) the baseband output is simultaneously applied to the overhead channel demodulator and, through a 7.5 MHz notch filter, to the receive TDM input.

i. The overhead channel demodulator output is a 0.3 - 100 KHz baseband which contains the four orderwire channels. These four VF orderwire and telemetry channels (points R, S, T) are interconnected to an orderwire channel patch board for use as required.

j. The input signal is further filtered in the TDM to complete formation of the 3-level partial response waveform and to band limit noise encountered during transmission. The TDM receive signal is then decoded, timing recovered, and demultiplexed to the appropriate ports of the VICOM receive TDM. The demultiplexed data emerges from each of the four or eight ports of the TDM as a T1 data stream.

k. The receive T1 data is applied to the input of the HN-74, through the digital patch board (point J). The HN-74 receive section decodes the 50%

bipolar (T1) input signal, recovers receive timing, and conditions the resulting data for input to the KG-34. After decryption by the KG-34, the receive data signal is applied to the input of the HY-12 channel bank through a level coverter module. The HY-12 receive section is clocked by timing recovered in the HN-74. It obtains frame synchronization from the overhead in the incoming data, and decodes the 8-bit binary words into a PAM data stream and the individual channel information pulses are applied to the respective 3.4 KHz low pass filter in each of the 24 receive channel units of the HY-12. The filter inputs are a replica of the distant end input information and need only be amplified for use. The HY-12 D2 channel outputs emerge at a +7 dBM level. External 7 db attenuation is required before the outputs appear at the VF equal level patch board.

1-4. Additional Test Capability:

a. In addition to the test equipment listed in the remaining attachments, the AFCS test facility capability is enhanced by the use of the time series analyzer. The time series analyzer is a digital processing system for broadband, high resolution analysis of analog output, and for general analysis, synthesis, and array manipulation of time series data. Based principally on the fast fourier transform algorithm, the system is capable of simultaneous two-channel analysis of data with bandwidths from DC to 50 KHz. The principal feature of the time series analyzer used during this test period was the

computation of the auto-power spectrum of the PCM VF channel. This computation is described briefly in the following paragraph.

b. The time series analyzer system includes a PDP 11/15 minicomputer with a 10 bit analog/digital converter. The computer accepts the raw PCM VF channel voltage (via the A/D converter) at a specified sampling frequency. This input voltage is converted into the frequency domain by means of the fast fourier transform. The complex value of each discrete frequency component is then multiplied by its complex conjugate and added to the values from the previous data frames, resulting in the computation of the auto-power spectrum. This computation is summarized by the following series of equations:

Time Domain	Fast Fourier Transform	Frequency Domain
1) $F_x(t)$		$F_x(S)$
2) Power Spectrum	$G_x(S)$ =	$F_x(S) \cdot F_x^*(S)$
3) Auto Power Spectrum	$\overline{G_x(S)}$ =	$\dfrac{\sum G_x(S) \text{ For each data frame}}{\text{Number of frames}}$

VF CHANNEL MEASUREMENTS

PART ONE

2-1. Objectives. The objective of this test series was to determine if a single assessment technique can be used to provide a figure of merit for a VF channel. It was also necessary to determine the amount of interchannel crosstalk within the TSEC/CY-104.

2-2. Discussion:

a. Normal loaded channel distortion measurements for a VF channel in an FDM system include phase jitter, harmonic distortion, and intermodulation distortion. These measurements may also be used to assess a VF channel in a PCM/TDM system. A S/N ratio measurement unique to a PCM/TDM system is quantizing distortion. Although each measurement technique requires a test tone to be inserted into the VF channel, each requires separate testing procedures and equipment. With the exception of phase jitter, the same phenomena in the channel is being measured (for example, the residual energy after notching out a test tone). A quantity is then assigned to this measurement to signify the qualitative condition of the channel. Although the measurement of the phenomena is similar and the channel condition is the same, a different

OPR: AFCS Digital Network Systems Facility/EPES
TEST ENGINEERS: Capt Wade Nielsen; Mr. Richard Girvin

quantity is generated for each test. Conceptually, a single measurement technique could be devised that performs a channel measurement which would relate to all the three measurements desired (quantizing distortion, harmonic distortion, and intermodulation distortion). The only remaining quantity to be measured would then be phase jitter. This could give a rapid indication, then, of both S/N ratio, in terms of a "figure of merit," and phase jitter.

b. One technique that can yield a figure of merit it to measure the detector output of a phase jitter test set with an RMS voltmeter. For example, the analog output of a TTI 1200 is derived by integrating the pulse error of the phase lock loop used to detect the amount of phase jitter. In the FILTER-OUT mode, this signal is proportional to most of the phase distortion signals present in the VF channel. To validate this technique, it was necessary to first investigate the technique under carefully controlled conditions, and then to compare this technique with present quantizing and harmonic distortion measurement techniques.

c. The final measurement taken was crosstalk.

2-3. <u>Test Procedures</u>:

a. Validation of Technique.

(1) *Two-tone Calibrations*. The first step in validating the use of a TTI 1200 and an RMS voltmeter was to determine the results of using two test

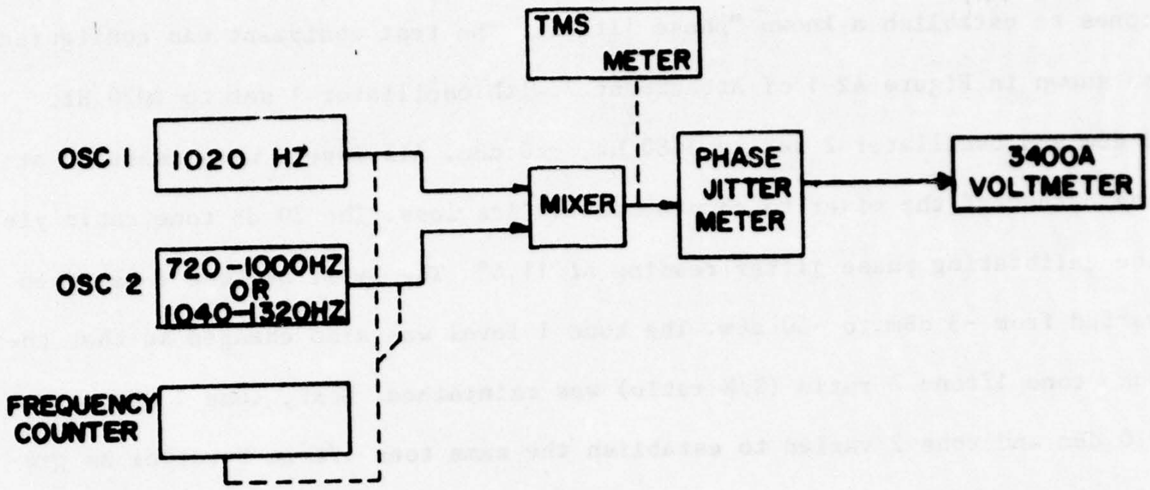
tones to establish a known "phase jitter." The test equipment was configured as shown in Figure A2-1 of Attachment 2 with oscillator 1 set to 1020 Hz, Ø dBm and oscillator 2 set to 1080 Hz, -20 dBm. All levels were measured at the output of the mixer to compensate for its loss. The 20 dB tone ratio yields the calibtating phase jitter reading of 11.4°. The level of tone 2 was then varied from -3 dBm to -60 dBm. The tone 1 level was also changed so that the same tone 1/tone 2 ratio (S/N ratio) was maintained. Next, tone 1 was set to -20 dBm and tone 2 varied to establish the same tone 1/tone 2 ratios as previously obtained.

(3) *Frequency Dependency.* The above procedures were repeated except that the frequency of tone 2 was varied. With tone 2 at frequencies above 1320 and below 720 Hz the FILTER-OUT mode was used to obtain a reading, as the TTI 1200 analyzes a broader bandwidth in the FILTER-OUT mode than in the FILTER-IN mode.

(4) *Analog Signal Investigation.* Finally, the analog output of the TTI 1200 was analyzed to determine its frequency components. Power spectrum plots were made using the time series analyzer. (A brief description of this analyzer is found in Attachment 1, paragraph 1-4.)

b. Comparison of Techniques:

(1) *General Procedures.* With the common measurement technique validated under controlled conditions, the next step was to compare the figure of merit with quantizing and harmonic distortion measurements. These three techniques were used to measure channels 2, 6, 7, 8, 9, 10, 11, 13, 14, 15, 19,



EQUIVALENT S/N CALIBRATION TEST CONFIGURATION

Figure A2-1

TEST EQUIPMENT

Nomenclature	Manufacturer	Model #	Serial #	Cal Due
Trans. Meas. Set	HP	3550	129-ØØ28	22 Nov 73
Digital Osc.	HP	4204A	12Ø4JØ276Ø	16 Feb 74
Test Oscillator	HP	654A	Ø951AØ1132	4 Nov 73
Electronic Counter	HP	5245L	1124A23748	13 Mar 74
Phase Jitter Mtr.	TTI	1200	256	28 Dec 73
RMS Voltmeter	HP	3400A	4Ø1-Ø1142	10 Nov 73

Test Equipment Requirement For Figure A2-1

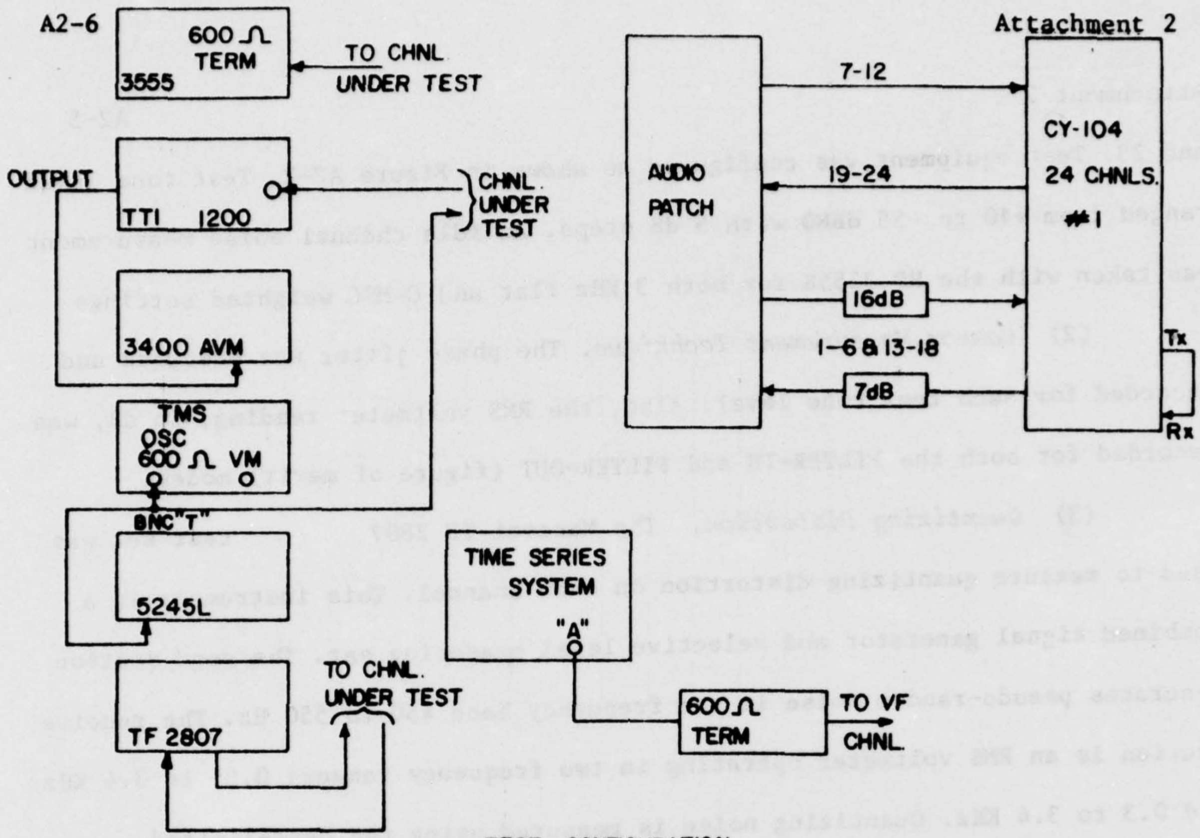
Table A2-1

and 23. Test equipment was configured as shown in Figure A2-2. Test tone level ranged from +10 to -55 dBM0 with 5 dB steps. An idle channel noise measurement was taken with the HP 3555B for both 3 KHz flat and C-MSG weighted settings.

(2) *Common Measurement Technique.* The phase jitter was measured and recorded for each test tone level. Also, the RMS voltmeter reading, in dB, was recorded for both the FILTER-IN and FILTER-OUT (figure of merit) modes.

(3) *Quantizing Distortion.* The Marconi TF 2807 test set was used to measure quantizing distortion on each channel. This instrument is a combined signal generator and selective level measuring set. The send section generates pseudo-random noise in the frequency band 450 to 550 Hz. The receive section is an RMS voltmeter operating in two frequency ranges: 0.85 to 3.4 KHz and 0.3 to 3.4 KHz. Quantizing noise is measured using the band-limited pseudo-random noise as the transmit channel stimulus. At the receiver end, quantizing noise is the ratio of the noise-plus-distortion measurement (0.3 to 3.4 MHz) to the noise only measurement (0.85 to 3.4 KHz). Procedures for this measurement were followed according to the manufacturer's manual.

(4) *Harmonic Distortion.* The harmonic content of a test tone loaded VF channel was recorded by the use of a power spectrum plot of the channel. This power spectrum was obtained using the time series analyzer Model 1923. Except for channels 2 and 7, plots were made only of test tones at +10, -10, and -30 dBmØ levels. For channels 2 and 7, a plot was made of each test tone level used (+10 to -55 dBmØ in 5 dB steps). An idle channel plot was also made for each channel.



TEST CONFIGURATION

Figure A2-2

Nomenclature	Manufacturer	Model #	Serial #	Cal Due
Transmission and Noise Meas. Set	HP	3555B	Ø992AØ1924	10 Mar 74
Phase Jitter Mtr.	TTI	1200	256	28 Dec 73
RMS Voltmeter	HP	3400A	8Ø6-Ø9157	2 Feb 74
Trans. Meas. Set	HP	3550	829-ØØ218	17 Feb 74
Electronic Count.	HP	5245L	1124A23748	13 Mar 74
PCM Mux. Tester	Marconi	TF 2807	2423Ø1/2Ø	1 Nov 73
Time Series Anal.	Time Data	1923	196	

Test Equipment Requirement
For Figure A2-2

Table A2-2

c. Interchannel Crosstalk. For this test cross talk was measured in channels in both the physical and sampling sequence. The sequences are shown in Table A2-3. The Marconi TF 2807 was used following the manufacturer's procedures of operation. A 325 Hz test tone was transmitted in one channel and any resulting 325 Hz signal was measured in the adjacent channels.

2-4. <u>Results</u>:

a. Establishment of a common measurement technique: Figure A2-3 summarizes the data gathered in paragraph 2-3a *above*. When the frequency of tone 2 was varied, no variance was noted. As shown in the figure, the RMS voltmeter readings were found to be directly proportional to the actual tone 1/tone 2 ratio. This indicates that this method may be valid if it also compares to quantizing and harmonic distortion measurements.

b. Comparison of Techniques.

(1) *Figure A2-4* compares the results of the quantizing, distortion measurement, and the figure of merit readings.

(2) *Figure A2-5 through A2-8* show a typical channel's plots for various test tone levels. Because of the low sampling frequency of 20.48 KHz used in Figures A2-5 through A2-8, spurious frequencies appear. Some of the more predominant spurious frequencies are 3.52 KHz and 4.88 KHz. These were caused by a high 8 KHz tone and its harmonic 16 KHz (which is not seen in these figures

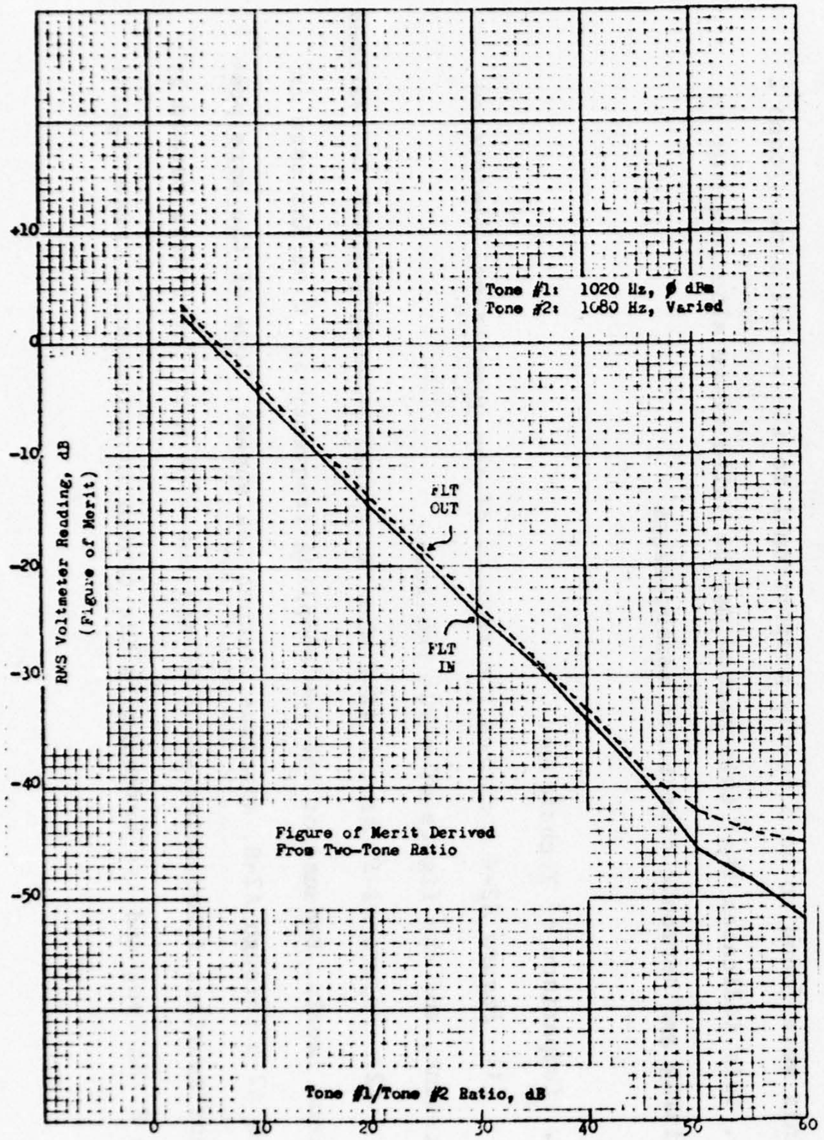


Figure A2-3

CROSSTALK CHANNELS

Transmit Channel X,S	Receive Channels X+1	X+2	X-1	X-2	S+1	S+2	S-1	S-2
2	3	4	1	24	18	6	14	11
6	7	8	5	4	22	10	[illegible]	2
7	8	9	6	5	23	11	19	3
9	10	11	[illegible]	7	15	3	21	5
10	11	12	9	8	16	4	22	6
11	12	13	10	9	14	2	23	7
13	14	15	12	11	1	17	12	24
14	15	16	13	12	2	[illegible]	11	23
15	16	17	14	13	3	19	9	21
18	19	20	17	16	6	22	2	14
19	20	21	18	17	7	23	3	15
23	24	1	22	21	11	14	7	19

X = Physical Sequence

S = Sampling Sequence

Table A2-3

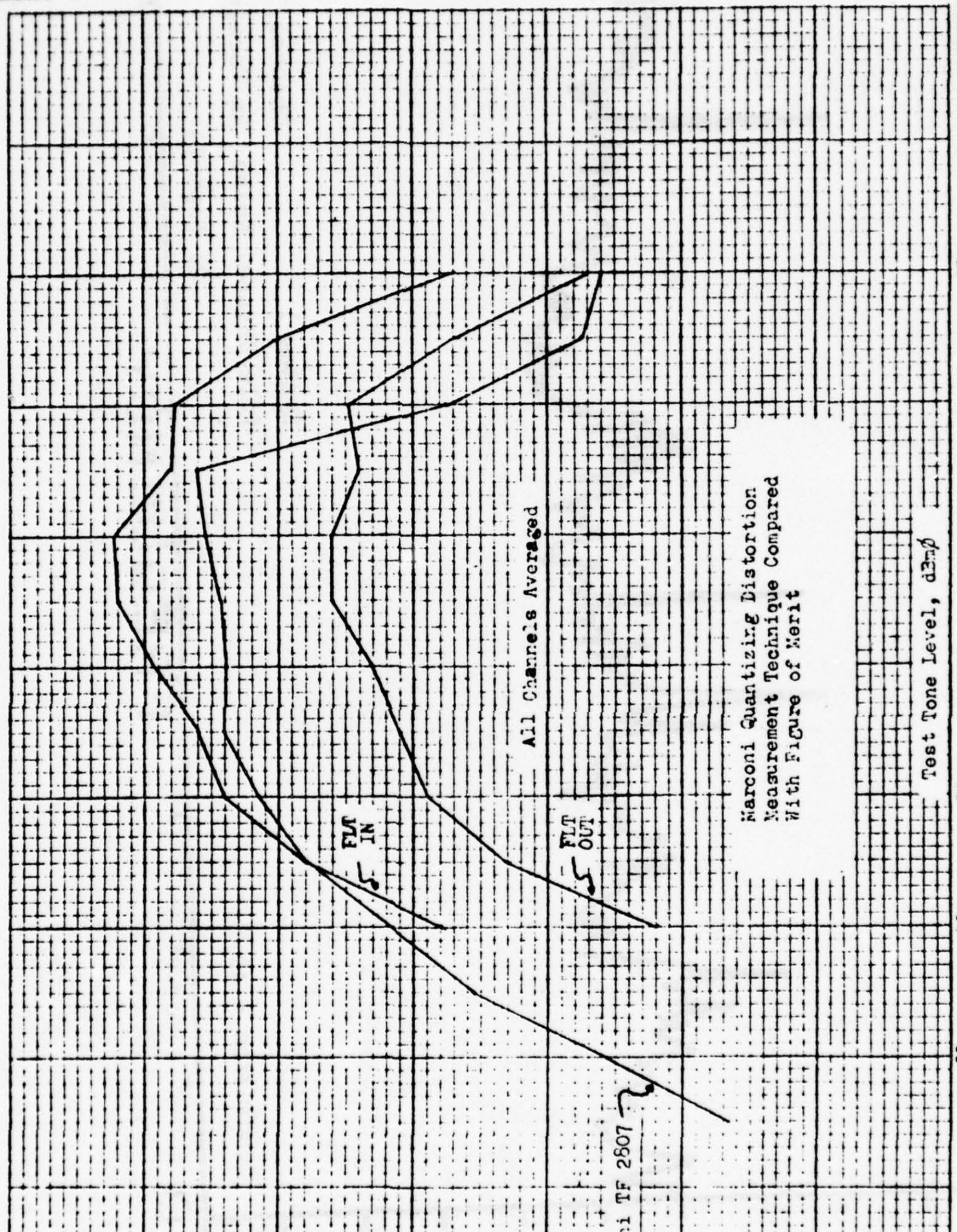

Marconi Quantizing Distortion
Measurement Technique Compared
With Figure of Merit
All Channels Averaged
FLT IN
FLT OUT
Marconi TF 2807
Test Tone Level, dBm0
S/N in dB
(Figure of Merit)
+10
0
-10
-20
-30
-40
-50
40
30
20
10

Figure A2-4

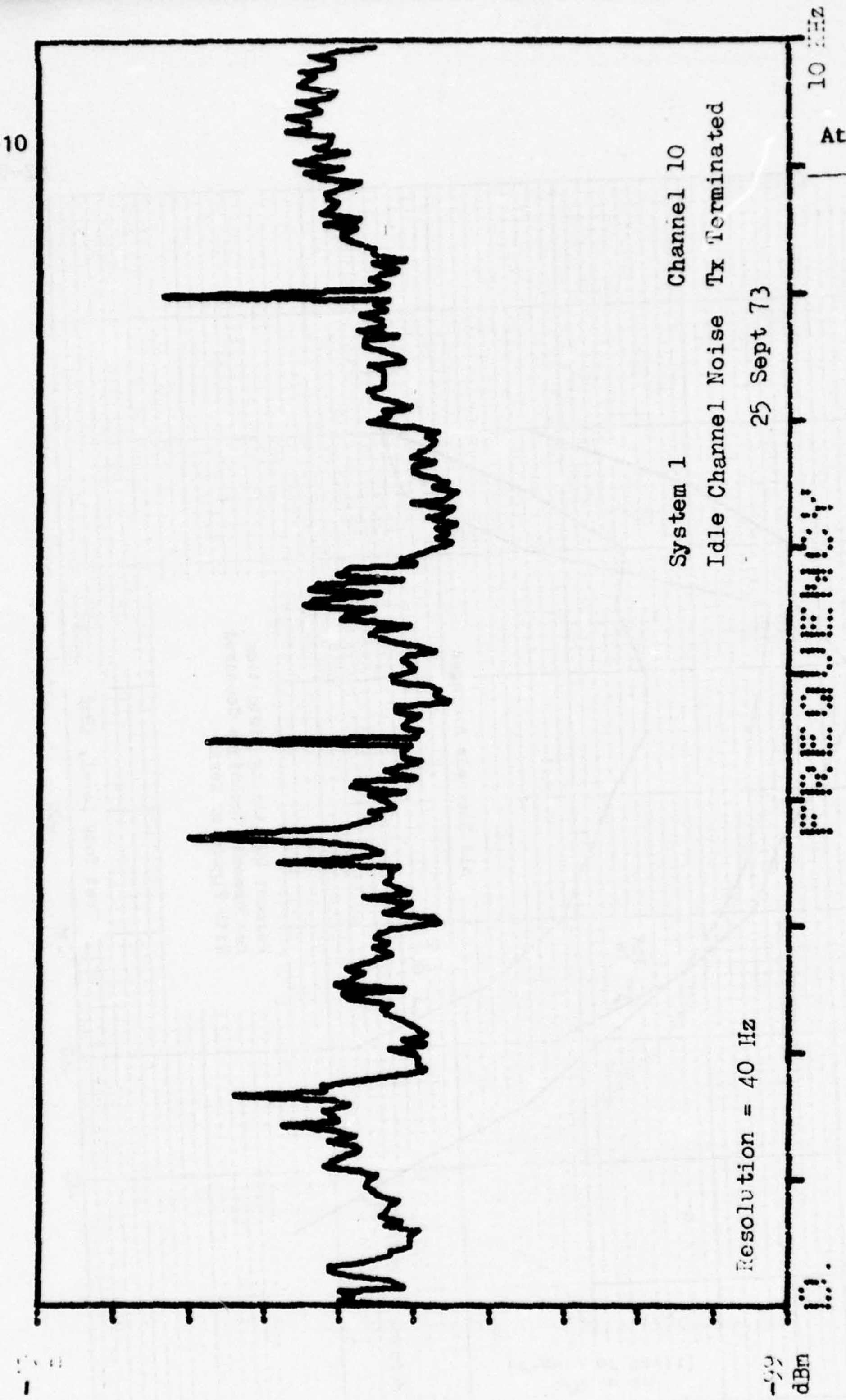

System 1
Channel 10
Idle Channel Noise Tx Terminated
25 Sept 73
Resolution = 40 Hz
FREQUENCY
0.
10 KHz
-99
dBm

Figure A2-5

Attachment 2

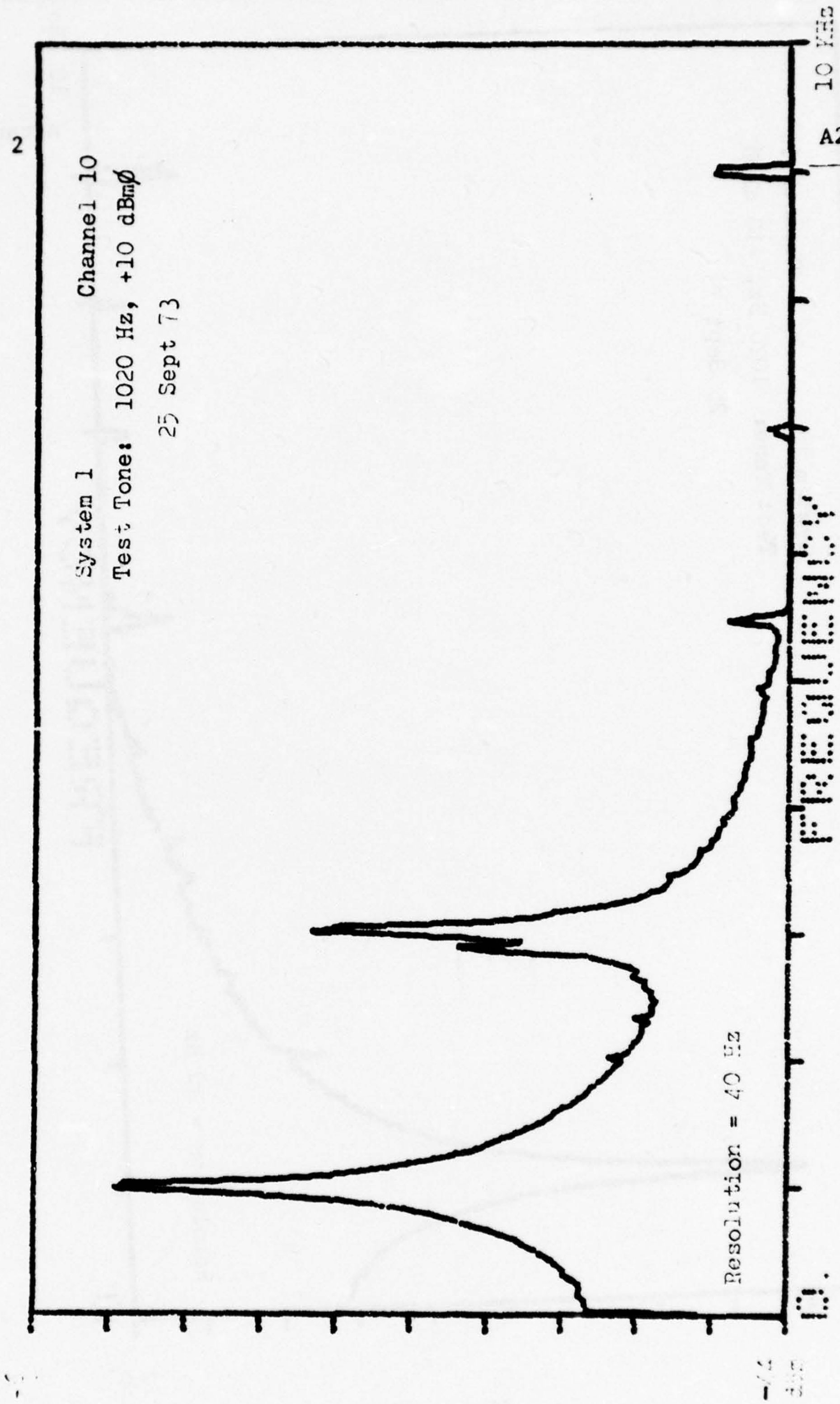


Figure A2-6

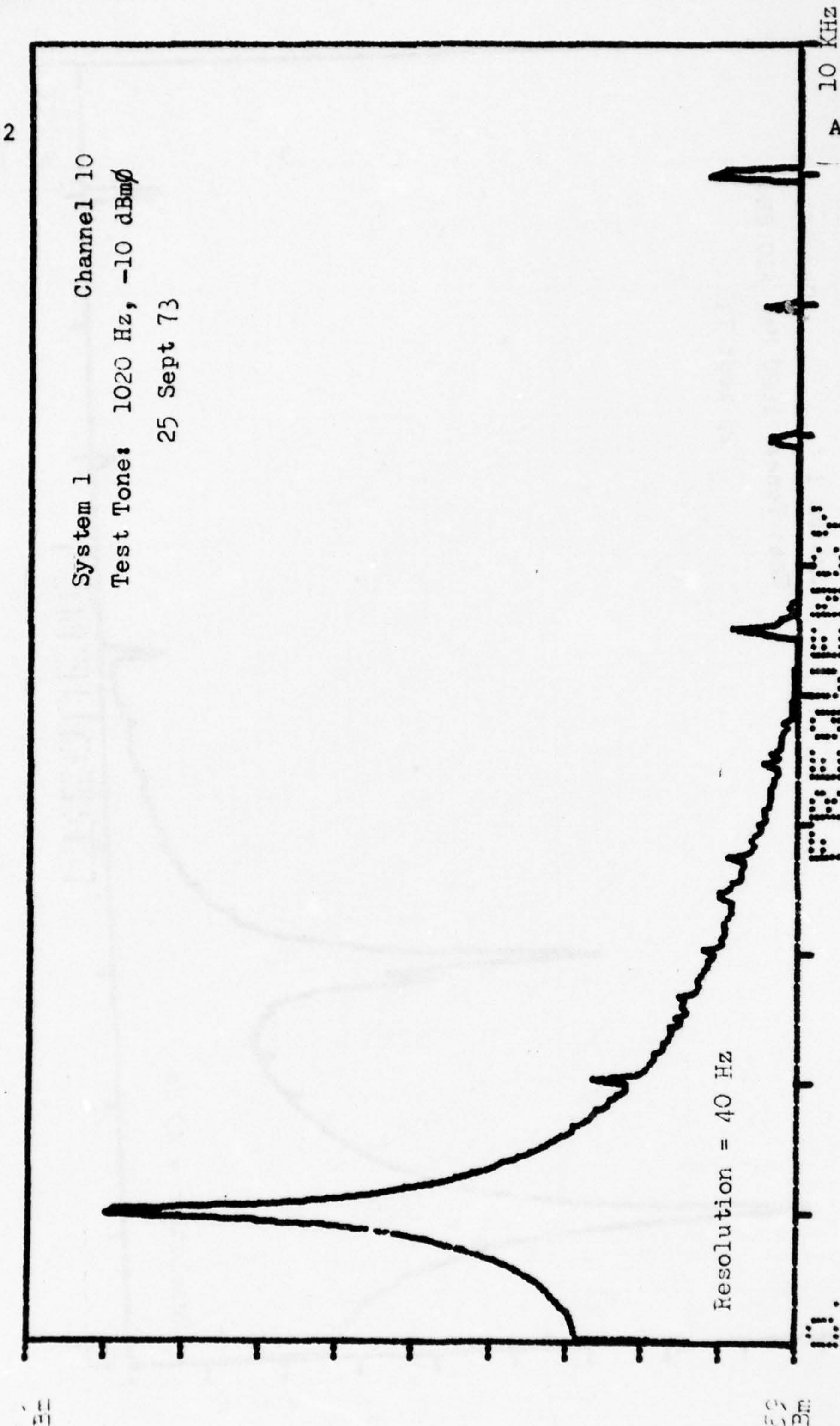

System 1
Channel 10
Test Tone: 1020 Hz, -10 dBm0
25 Sept 73
Resolution = 40 Hz
FREQUENCY
0.
10 KHz
dBm

Figure A2-7

Attachment 2

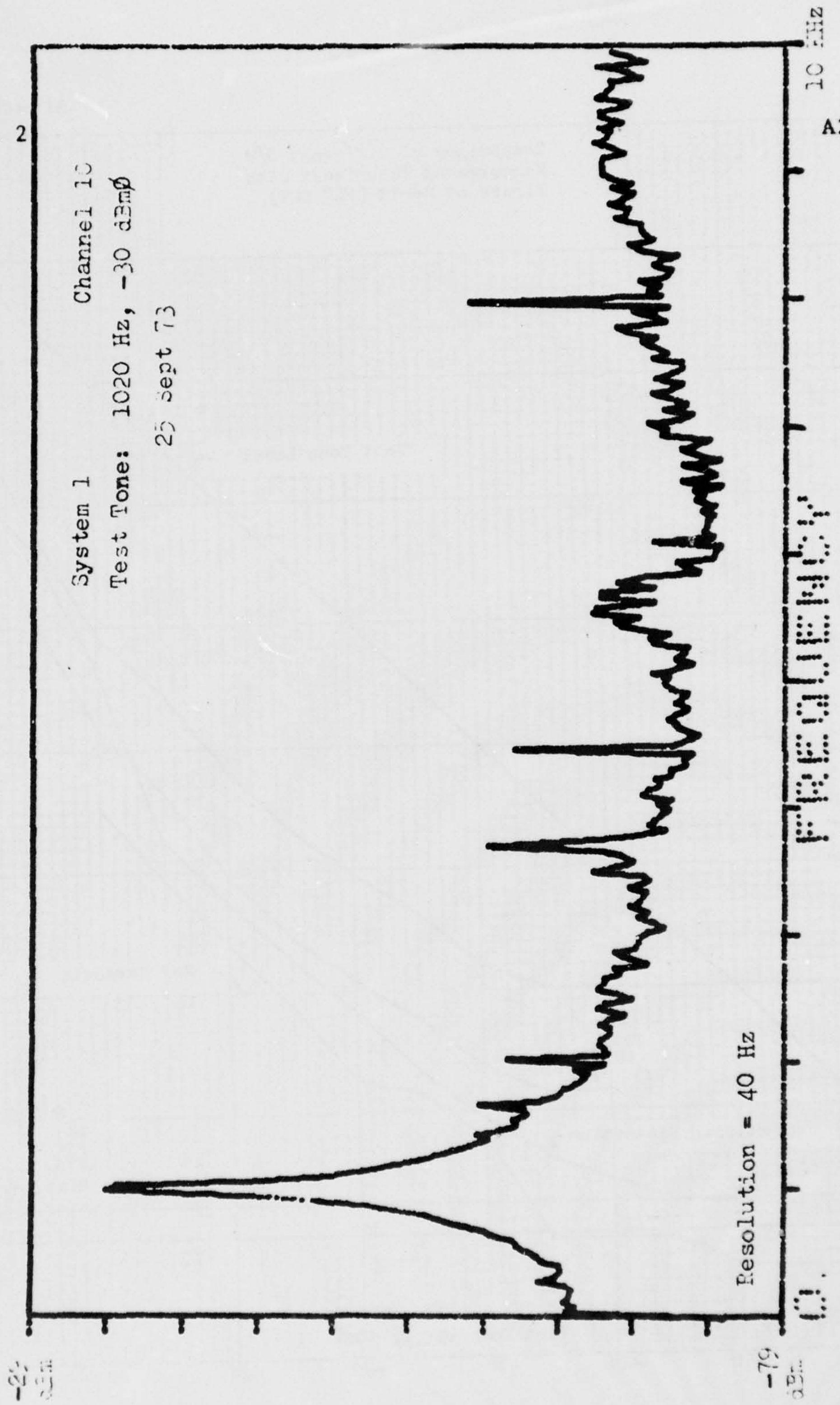
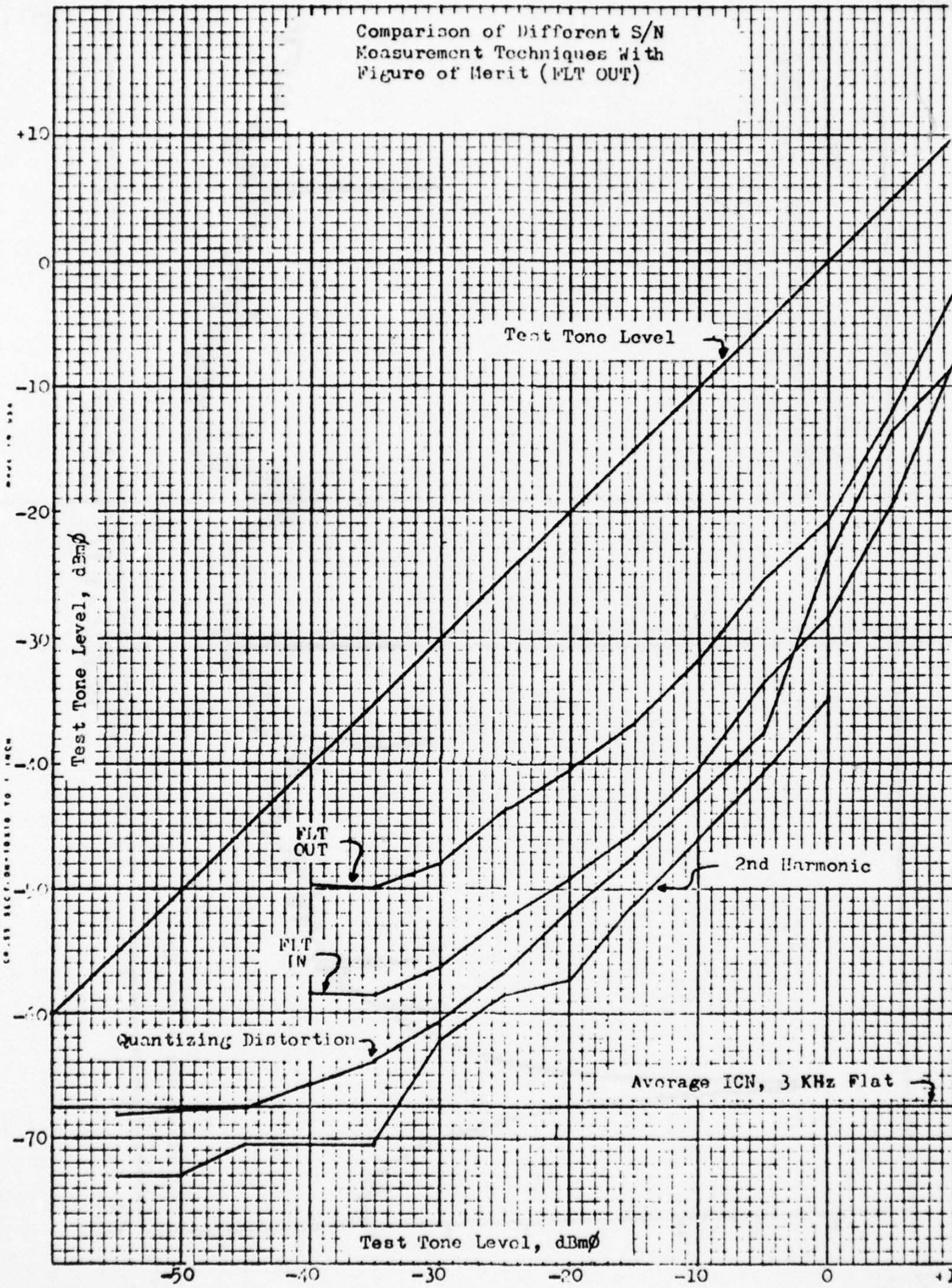


Figure A2-8



Comparison of Different S/N Measurement Techniques With Figure of Merit (FLT OUT)
+10
0
-10
-20
-30
-40
-50
-60
-70
Test Tone Level, dBmØ
Test Tone Level
FLT OUT
FLT IN
2nd Harmonic
Quantizing Distortion
Average ICN, 3 KHz Flat
Test Tone Level, dBmØ
-50
-40
-30
-20
-10
0
+10

Figure A2-9

but which has been measured and found to be only a few dB lower than the 8 KHz tone) and the time series analyzer sampling frequency of 20.48 KHz. Second harmonic levels were read directly from the channel power spectrum plots and found to remain constant at 35 dB down from the fundamental frequency for varying levels of the test tone from Ø to -35 dBm. This is shown in Figure A2-9.

(3) *Figure A2-9* summarizes quantizing and harmonic distortion, idle channel noise, test tone levels, and figure of merit values (FILTER OUT). This figure reflects that the common measurement technique positively correlates with quantizing and harmonic distortion. Within the test tone level range-15 to -30 dBmØ, the FILTER-IN readings (for a 1020 Hz test tone) differ by 6 to 8 dB from both quantizing and harmonic distortion measurement. For the same interval, the FILTER-OUT mode readings differ by 17 dB. At test tone levels higher than -5 dBmØ, the quantizing distortion comes within 1-2 dB of the FILTER-OUT readings. At low test tone levels, for example, less than -30 dBmØ, both RMS voltmeter readings begin to approach the test tone level.

(4) It must be noted that the measured analog signal from TTI 1200 is a result of the VF channel phase jitter. Tests to determine how sensitive the common measurement technique is to amplitude distortion will be conducted in future testing.

c. Interchannel Crosstalk. Table A2-4 summarizes the results of the interchannel crosstalk measurements. With a Ø dBmØ test transmitted, the resulting crosstalk is seen to be far below the idle channel noise for channels both in physical and sampling proximity.

INTERCHANNEL CROSSTALK
Marconi TF-2807 Method

3[illegible]5 Hz Transmitted Test Tone Level	Received Tone Level, dBm∅ All Channels Averaged X+1	X+2	X-1	X-2	S+1	S+2	S-1	S-2
∅ dBm∅	-78.4	-78.9	-79	-78.3	-76.6	-77.8	-76.4	-78
+1∅ dBm∅	-6[illegible].7	-6[illegible].1	-68.1	-67.5	-69.9	-64.8	-67.5	-68.1
ICN 3 KHz Flat Weighted	-68	-67.4	-67.6	-67.2	-67.6	-67.4	-67.4	-67.7

Table A2-4

PART TWO - D-2 VF CHANNEL CHARACTERISTICS VS T1 BER

2-5. Objective. The purpose of this test was to determine the correlation between T1 BER and D-2 channel bank characteristics. The D-2 characteristics examined were frame error indications and the amplitude distribution of the VF idle channel impulses which result from bit errors in the T1 data stream. T1 BER was also correlated with the baseband S/N ratio.

2-6. Discussion. These test objectives were developed to aid in the establishment of both an in-service and an out-of-service testing technique.

a. In-Service Test Technique.

(1) One in-service method of determining T1 BER is to count the number of D-2 framing errors in a given period of time. D-2 frame errors are directly related to T-1 bit errors because the probability of a frame bit being in error is the same as that of any other T1 bit being in error. Each time a frame bit is detected as being in error, an error flip-flop circuit generates a pulse. By counting these pulses for an interval of time, the T1 BER can be determined, and hence the quality of the 24 VF channels composing one T1 data stream can be determined.

(2) Counting the frame error flip-flop pulses is simply a matter of connecting an electronic counter to the flip-flop output on the VICOM 7030 receive Common unit as indicated in Figure A2-10. This count must then be correlated to the T1 BER.

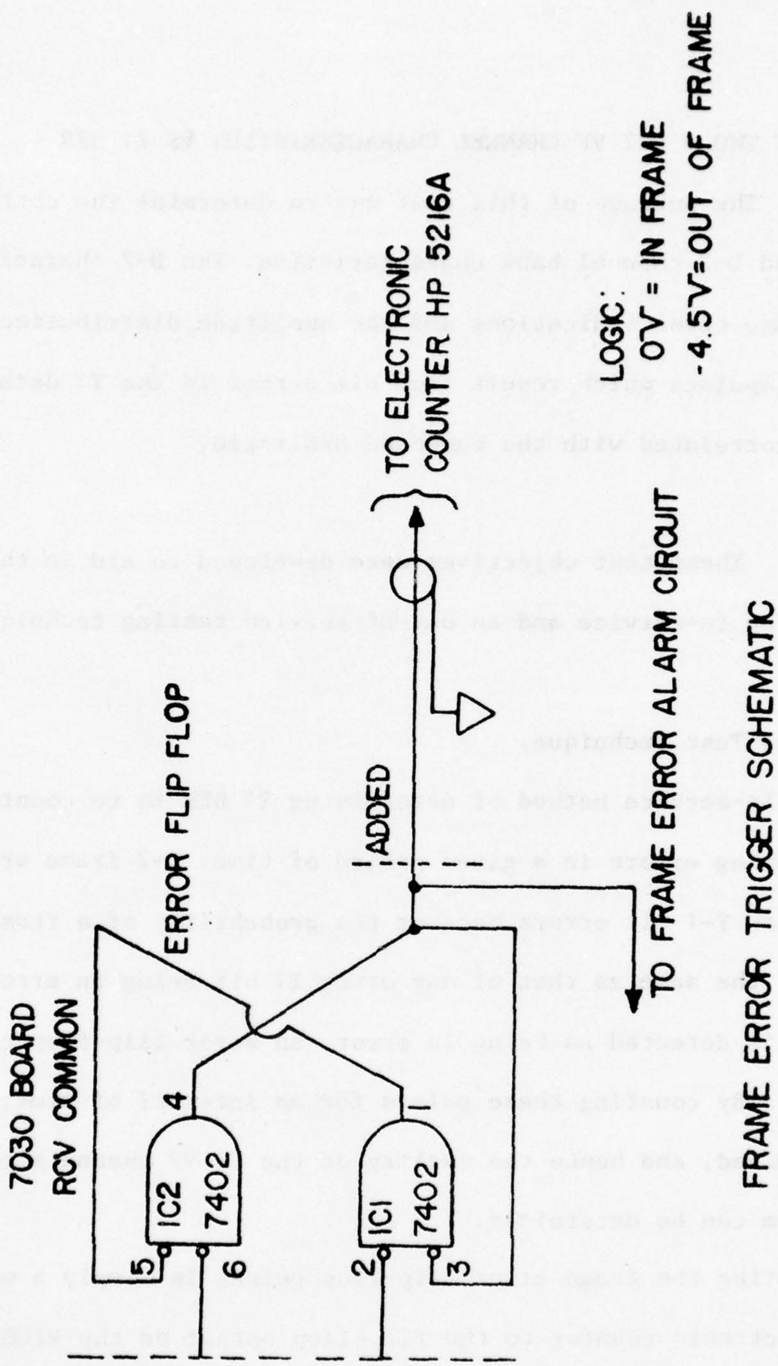
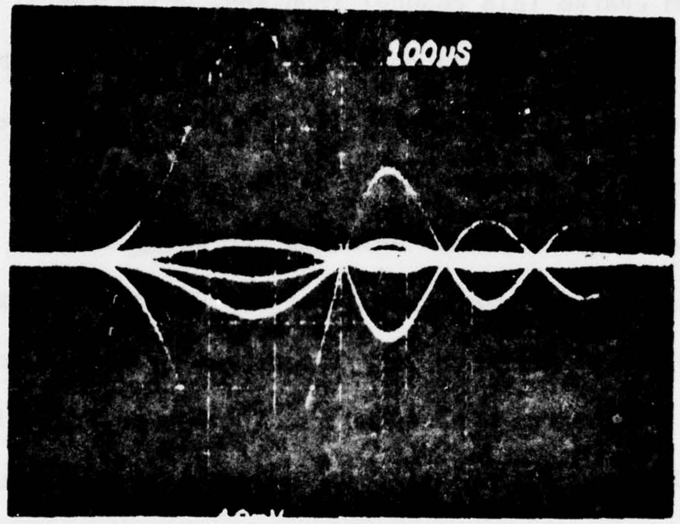

7030 BOARD
RCV COMMON
IC2
7402
IC1
7402
5
6
4
2
3
1
ERROR FLIP FLOP
ADDED
TO ELECTRONIC
COUNTER HP 5216A
LOGIC:
0V = IN FRAME
-4.5V=OUT OF FRAME
TO FRAME ERROR ALARM CIRCUIT
FRAME ERROR TRIGGER SCHEMATIC

Figure A2-10

b. Out-of-Service Test Technique.

(1) *Impulse Counting.* Current FDM out-of-service impulse counting techniques use mechanical counters set at levels established by DCA (vis, -18, -28, and -38 dBm0). In an FDM system, VF channel impulses may assume any value, whereas in a PCM/TDM system idle channel impulses, which result from T1 bit errors, will assume discrete levels depending on which bit in the PCM word is errored. This discrete level characteristic is shown in a time exposure photograph of several impulses in Figure A2-11. Table A2-5 tabulates the relative dB values of impulses resulting from selected PCM words.

(2) *Amplitude Histograms.* Because of the discrete amplitude levels of impulse noise in a PCM system and the randomness of their occurrence, it is worthwhile to determine the amplitude histogram at several T1 bit-error rates. This was done by a careful examination of the T1 data decoding process. Figure A2-12 shows that bits 2, 3, and 4 (left to right) of the PCM word determine the eight major amplitude encoding/decoding segments. Bit 1 determines the sign. Bits 5, 6, 7, and 8 determine the 16 levels within each major amplitude segment. Because these four bits do not significantly contribute to the amplitude of the PAM pulse, only impulse noise resulting from bits 2, 3, or 4 need be counted. The circuit of Figure A2-13 was designed to produce a trigger pulse when a selected VF channel has an impulse whose amplitude segment is determined by bits 2, 3, or 4 (or any combination of these three bits). This pulse was then used to trigger the time series analyzer (explained in Attachment 1) and hence generate the histogram. The relative probabilities (amplitude distribution) of these impulses is shown in Figure A2-14.



Vertical Scale = 10 mv/division

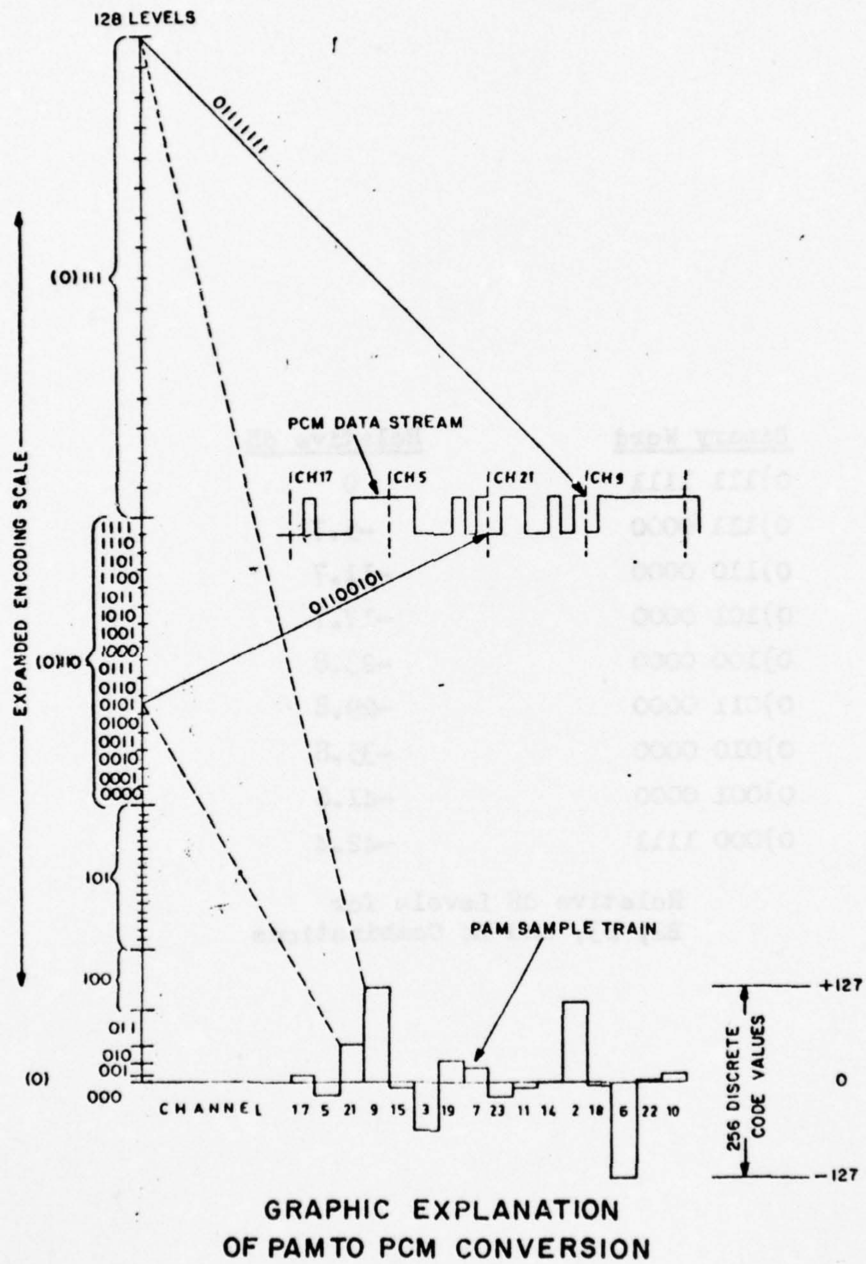
Multiple Idle Channel
Responses to Bit Errors

Figure A2-11

Binary Word	Relative dB
0)111 1111	0
0)111 0000	-5.7
0)110 0000	-11.7
0)101 0000	-17.7
0)100 0000	-23.8
0)011 0000	-29.8
0)010 0000	-35.8
0)001 0000	-41.8
0)000 1111	-42.4

Relative dB Levels for
B2, B3, and B4 Combinations

Table A2-5



128 LEVELS
01111111
(0)111
PCM DATA STREAM
CH17
CH5
CH21
CH9
01100101
EXPANDED ENCODING SCALE
1111
1110
1101
1100
1011
1010
1001
1000
(0)110
0111
0110
0101
0100
0011
0010
0001
0000
101
100
011
010
001
(0)
000
CHANNEL
17 5 21 9 15 3 19 7 23 11 14 2 18 6 22 10
PAM SAMPLE TRAIN
+127
256 DISCRETE CODE VALUES
0
−127
GRAPHIC EXPLANATION OF PAM TO PCM CONVERSION

Figure A2-12

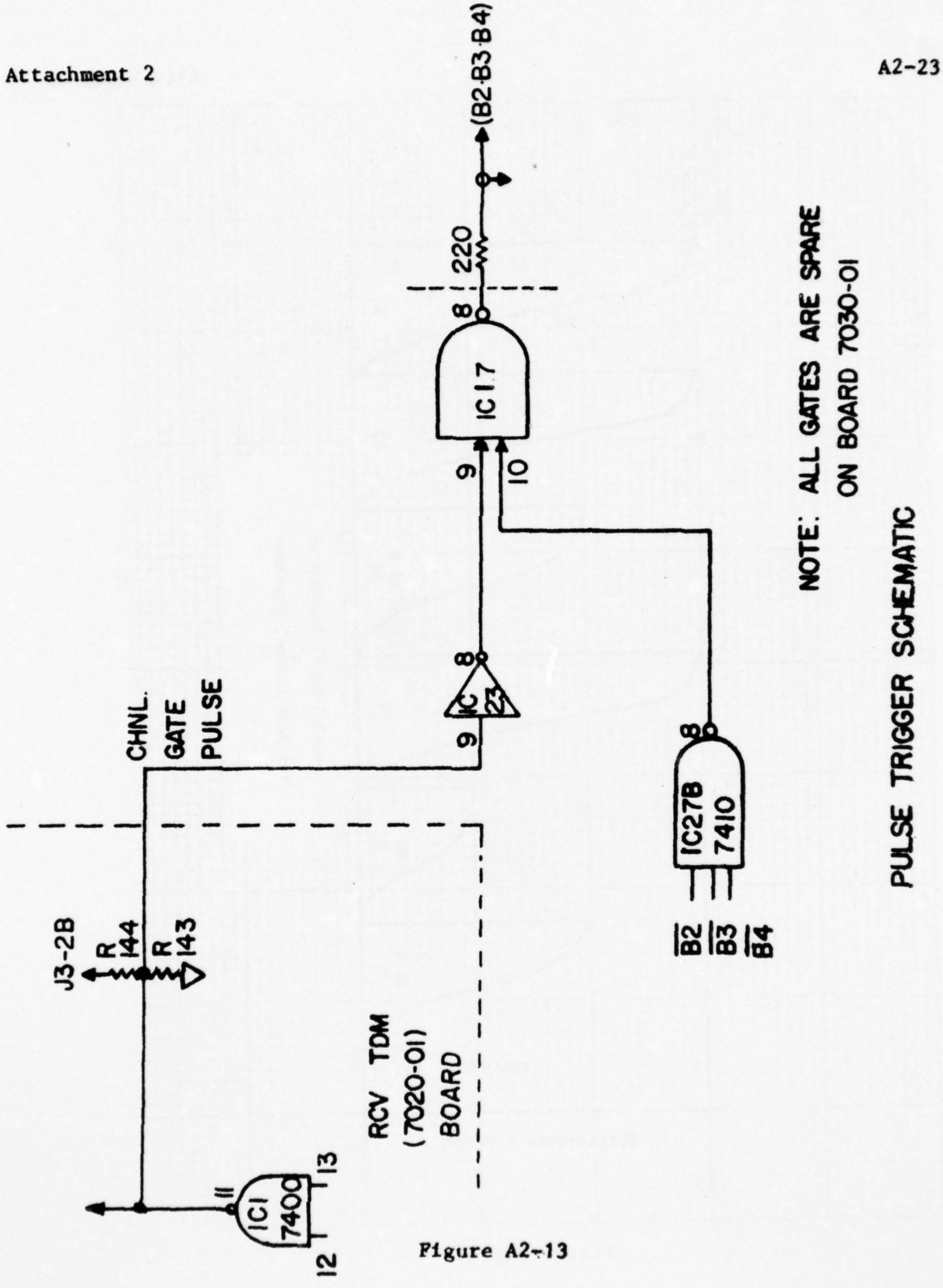

(B2·B3·B4)
220
8
IC 17
9
10
NOTE: ALL GATES ARE SPARE ON BOARD 7030-01
PULSE TRIGGER SCHEMATIC
CHNL. GATE PULSE
9
IC 23
8
IC27B 7410
$\overline{B2}$ $\overline{B3}$ $\overline{B4}$
J3-2B
R 144
R 143
RCV TDM (7020-01) BOARD
IC1 7400
11
12
13

Figure A2-13

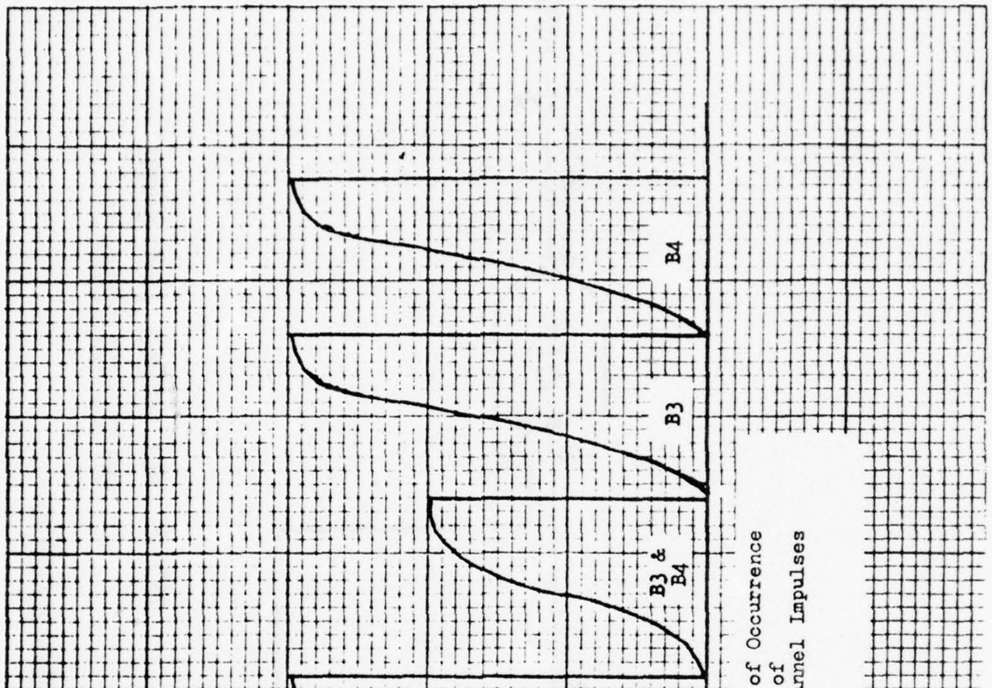

Probability of Occurrence
of
PCM Idle Channel Impulses
Relative Probability
B4
B3
B3 &
B4
B2
B2 &
B4
B2 &
B3
B2&B3&B4

Figure A2-14

(3) *T1 BER vs Baseband S/N*. A further relationship exists between each of the above testing techniques and the baseband signal-to-noise ratio. Exactly how they relate was determined by monitoring the baseband S/N ratio for each T1 BER.

2-7. Test Procedures. With the test equipment configured as shown in Figures A2-15 and A2-16, data was taken for five 5-minute periods for each of the following T1 bit error rates: $4X10^{-3}$, $1X10^{-3}$, $3X10^{-4}$, $1X10^{-4}$. Five 10-minute intervals were used for BERs of $3X10^{-5}$, $1X10^{-3}$, $3X10^{-6}$, and $1X10^{-6}$. For the bit error rate of $3X10^{-7}$, one 30-minute period was used. During each data sampling interval, the HP 5050B was used to automatically record the BER for monitoring purposes. Tests were conducted with the 4-port TDM connected back-to-back.

a. D-2 Frame Errors. The HP 5216A electronic counter was used to record the number of frame errors in the time period. It was manually gated on and off.

b. Impulse Noise. The ACTON 480A noise test set was set to approximate the DCA standard levels of -38, -28, and -18 dBmØ. The high level was set at -20 dBmØ because -18 dBmØ could not be achieved with the equipment used. The voice filter was used. The remaining impulse noise counters (TTS 58A) were set to -44, -38, -32, -38, -32, and -20 dBmØ respectively, again using the

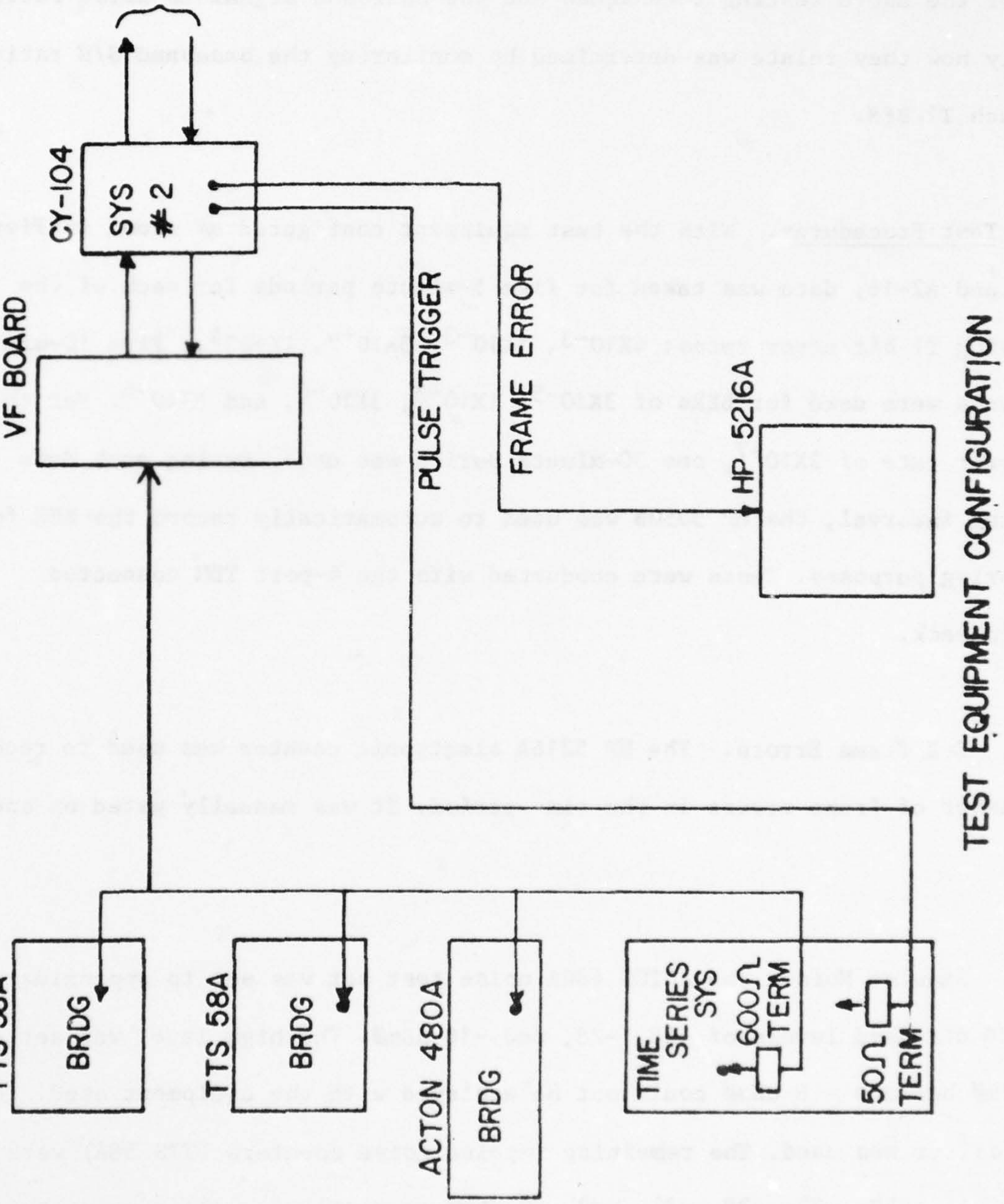

TEST EQUIPMENT CONFIGURATION
CY-104
SYS # 2
VF BOARD
PULSE TRIGGER
FRAME ERROR
HP 5216A
TTS 58A
BRDG
TTS 58A
BRDG
ACTON 480A
BRDG
TIME SERIES SYS
600Ω TERM
50Ω TERM

Figure A2-15

AD-A033 776 DIGITAL NETWORK SYSTEMS FACILITY (AFCS) RICHARDS-GEBA--ETC F/G 17/2
DCS OPERATIONAL TEST AND EVALUATION OF PCM/TDM EQUIPMENT.(U)
JUN 75

UNCLASSIFIED DNSF-TR-74-100 NL

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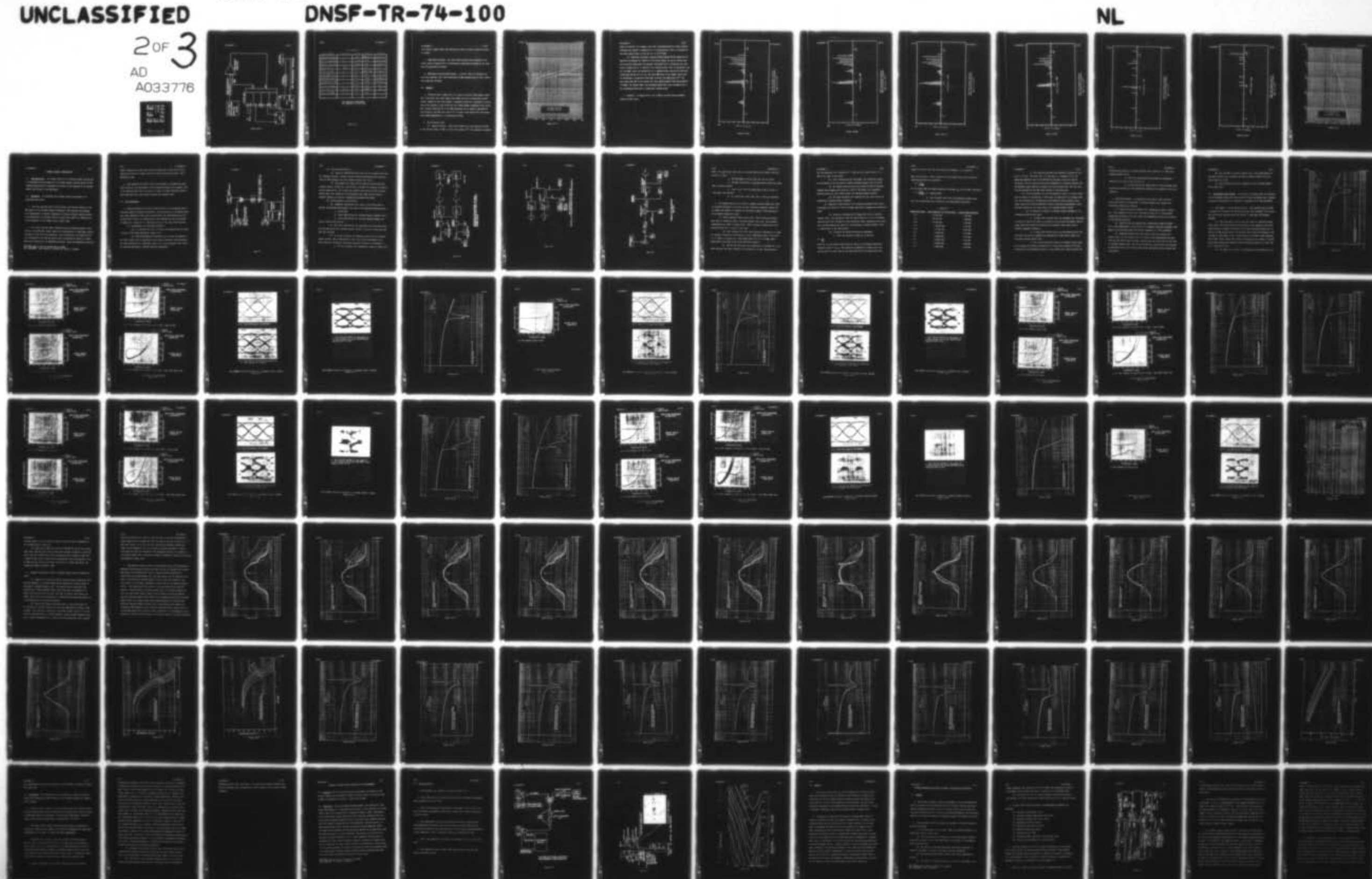

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2 OF 3

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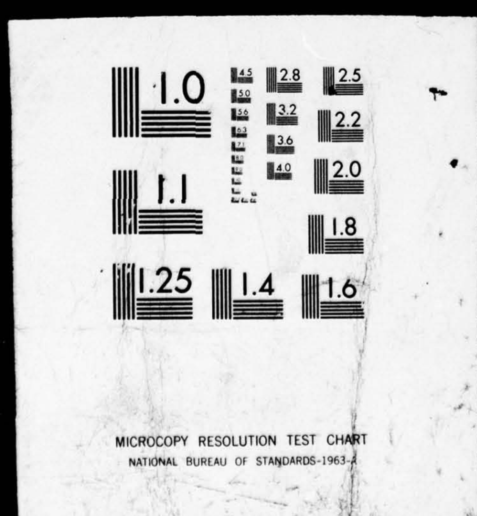


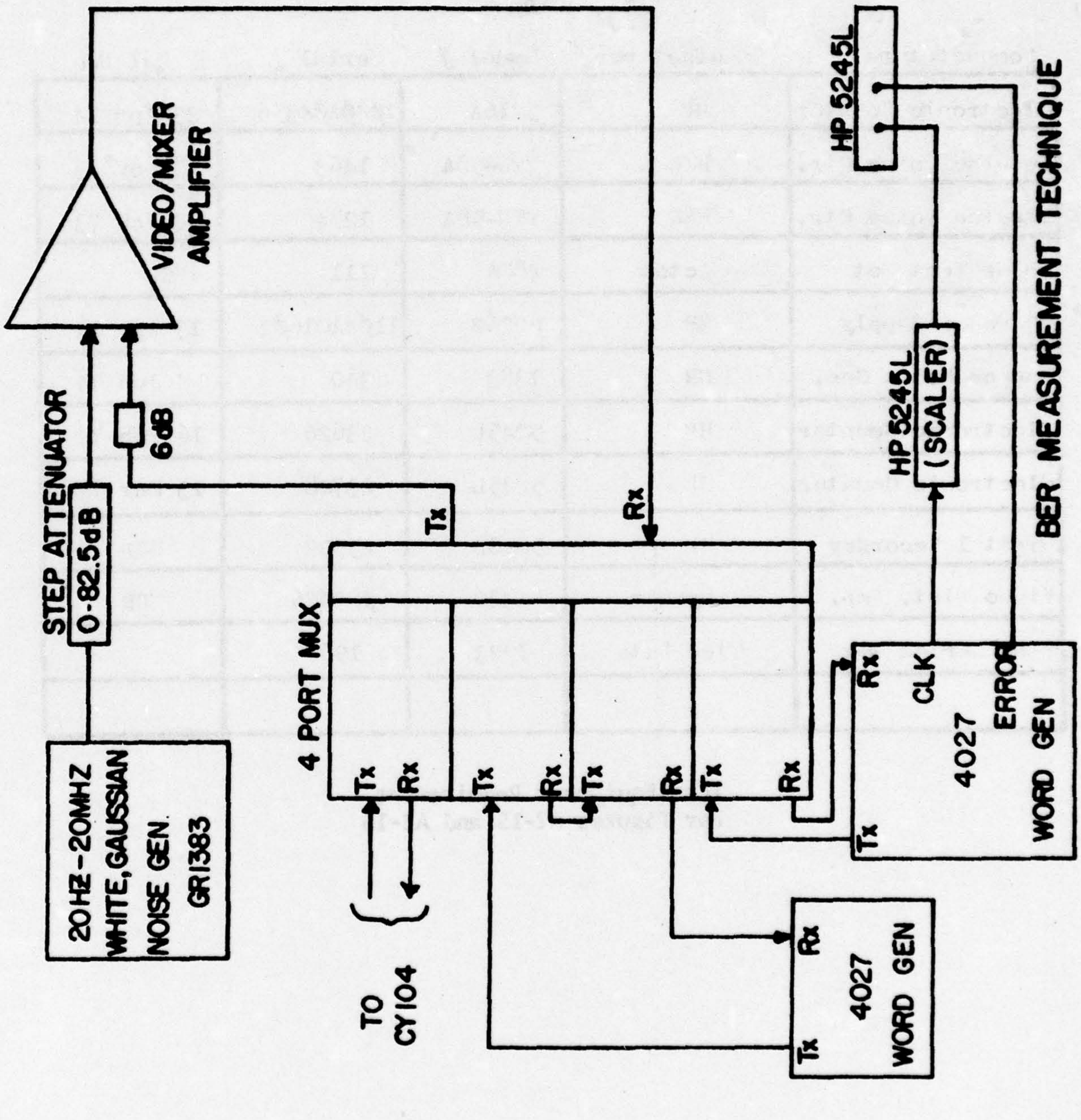

20HZ-20MHZ
WHITE, GAUSSIAN
NOISE GEN.
GR1383
STEP ATTENUATOR
0-82.5dB
6dB
VIDEO/MIXER
AMPLIFIER
4 PORT MUX
Tx
Rx
TO
CY104
4027
WORD GEN
HP 5245L
(SCALER)
HP 5245L
CLK
ERROR
BER MEASUREMENT TECHNIQUE

Figure A2-16

Test Equipment

Nomenclature	Manufacturer	Model #	Serial #	Cal Due
Electronic Counter	HP	5216A	1Ø4ØAØ4356	23 Apr 74
Impulse Noise Ctr.	NEC	TTS-58A	1463	7 Nov 73
Impulse Noise Ctr.	NEC	TTS-58A	1284	7 Nov 73
Noise Test Set	Acton	480A	111	NCR
DC Power Supply	HP	6226B	11Ø4A016Ø2	17 Apr 74
Random Noise Gen.	GR	1383	340	4 Jun 74
Electronic Counter	HP	5245L	23626	16 Feb 74
Electronic Counter	HP	5245L	23748	13 Mar 74
Digital Recorder	HP	5050B	25992	NCR
Video Dist. Amp.	Dynair	DA32C	Ø82Ø76	NCR
Time Series Ana.	Time Data	1923	196	

Test Equipment Requirement
For Figures A2-15 and A2-16

Table A2-6

voice filter. These levels were selected in order to yield a finer resolution of counts.

c. Amplitude Histogram. The time series analyzer was triggered by the output pulse of Figure A2-13. It performed an amplitude histogram of the peak level of each pulse received.

d. BER/Signal-to-Noise Relationship. At each T1 BER, the baseband S/N ratio was recorded. Also, the occurrences of TDM reframes and D-2 error lights were noted and recorded.

2-8. Results:

a. In-Service Data. Figure A2-17 is a plot of the D-2 frame errors versus the T1 bit-error rate. This figure also shows how the D-2 frame error counts closely compare to the total number of impulses counted by a mechanical counter. During the testing, it was noted that for a TDM reframe, hundreds of D-2 errors were counted. This was due to the TDM reframing action. However, the TDM did not reframe at low BER (less than 10^{-5}). At error rates above 10^{-5}, the system had already degenerated to an unacceptable level.

b. Out-of-Service Data:

(1) *Impulse Counters.* Figure A2-17 shows the total impulses counted by the TTS 58A versus T1 BER. At error rates above 10^{-4}, the mechanical counters

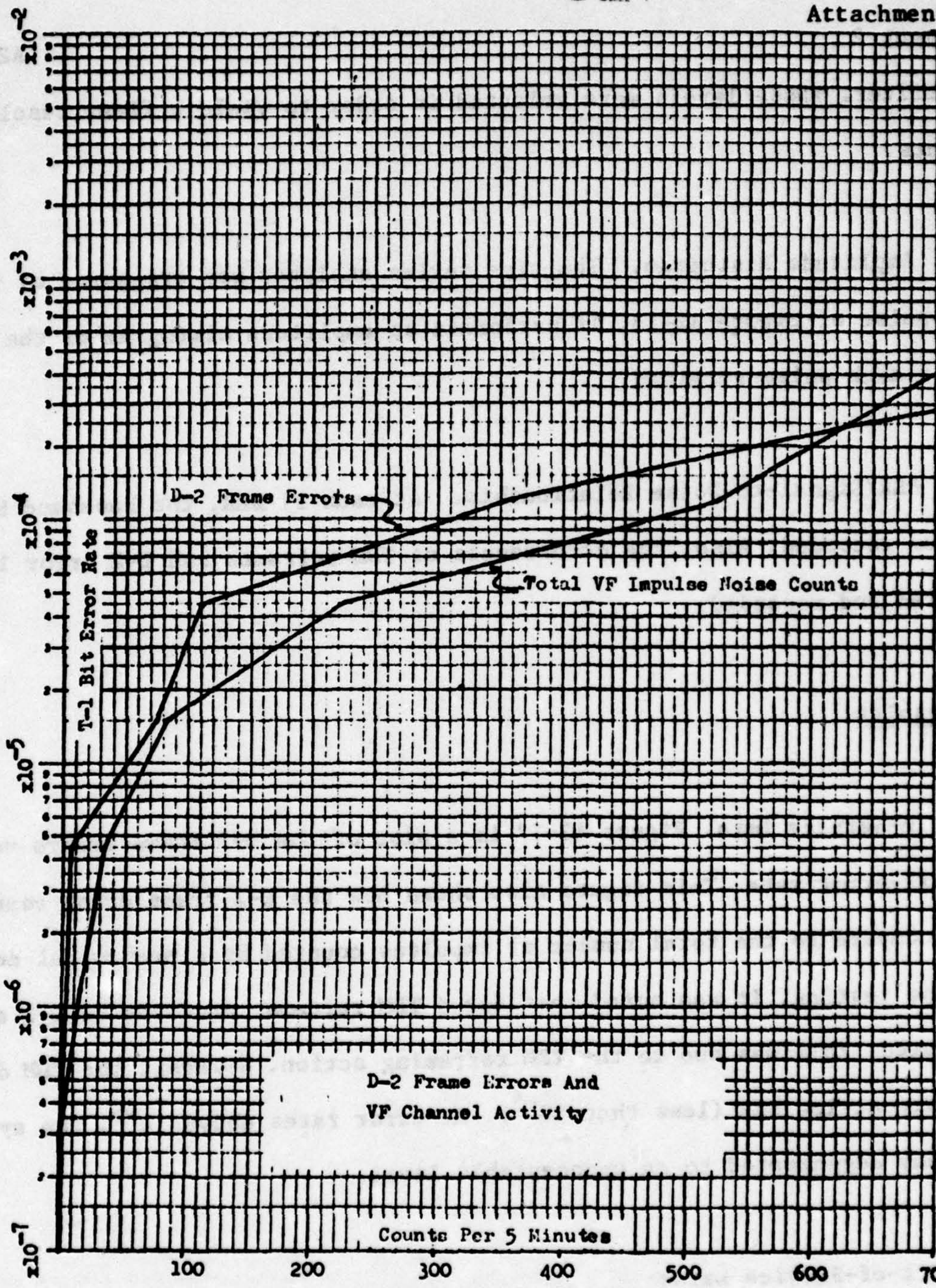

D-2 Frame Errors
Total VF Impulse Noise Counts
T-1 Bit Error Rate
D-2 Frame Errors And
VF Channel Activity
Counts Per 5 Minutes
x10^-2
x10^-3
x10^-4
x10^-5
x10^-6
x10^-7
100
200
300
400
500
600
700

Figure A2-17

began to saturate, for example, more than 7 pulses/second were being produced exceeding the counter's capability of 7.5 pulses/second. This is indicated by the sharp upward break of the plot at 1.2×10^{-4} BER.

(2) *Amplitude Histogram.* Figures A2-18a through A2-18f summarize the amplitude histograms for specific T1 bit-error rates. It can be readily seen that the pulse amplitudes are grouped. Each group can be attributed (as indicated in Figure A2-14) to specific bits being in error. This is especially true for low BERs, where the probability of a channel having consecutive PCM words containing errored bits is low. For high BERs some of the higher levels must be attributed to consecutive PCM words in error. For BERs below 10^{-5}, the data shows that 39% of all pulses will have levels greater than approximately -23 dBm0. For higher BERs, the percentage above this level increases due to the increasing occurrence of consecutive errored words.

c. Baseband. In Figure A2-19, the T1 BER is plotted versus baseband signal-to-noise ratio.

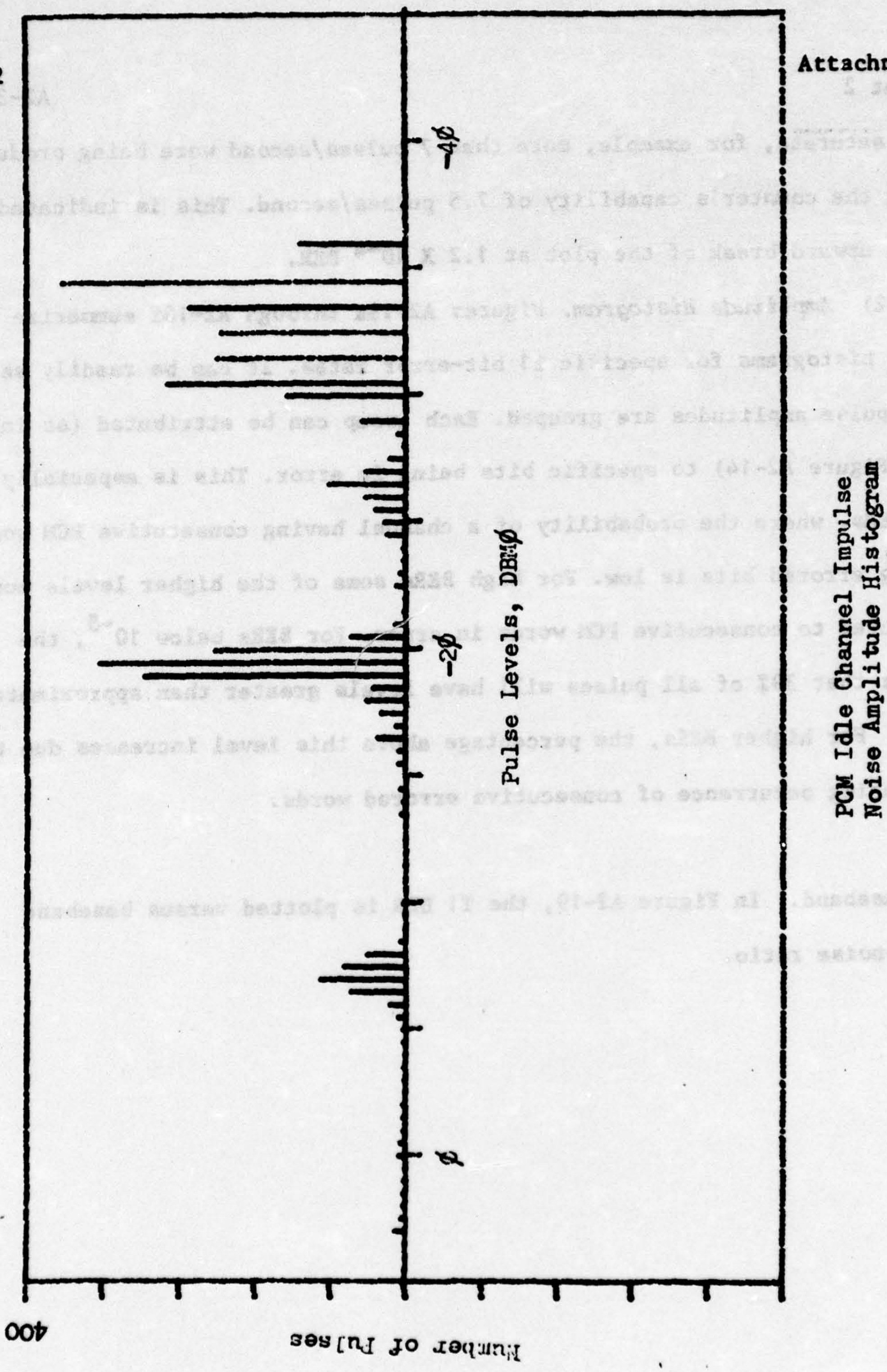


Figure A2-18a

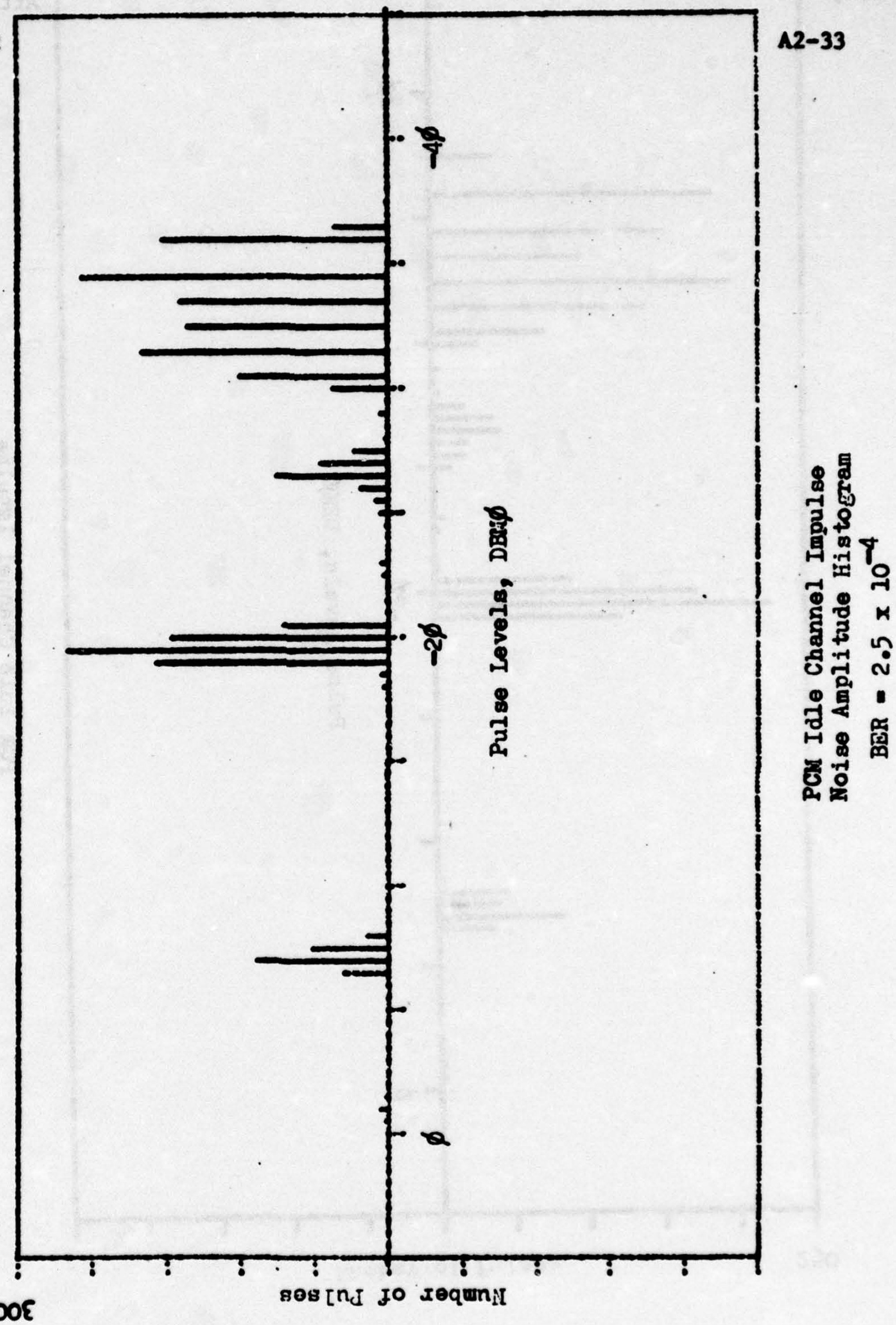
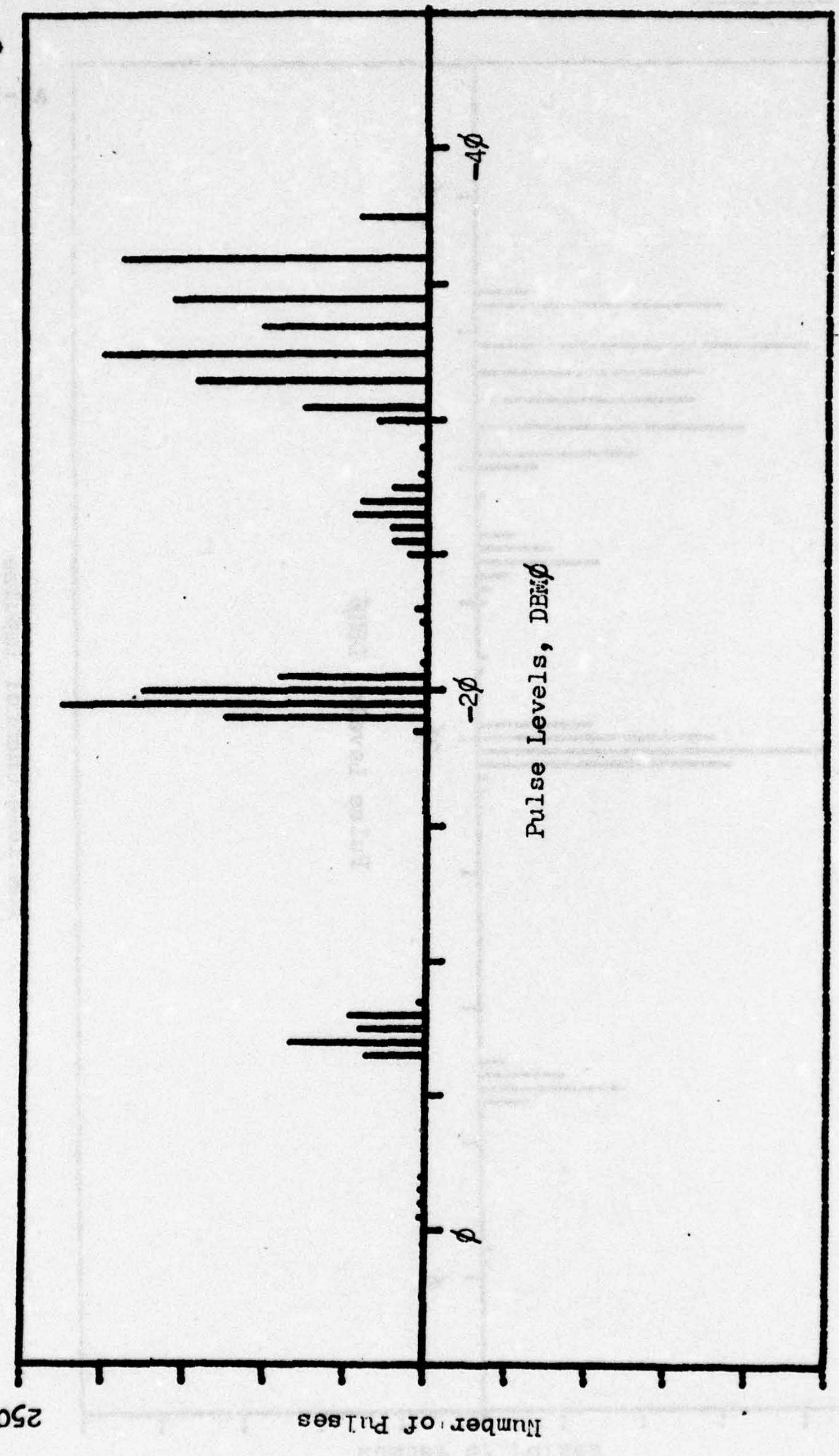


Figure A2-18b



PCM Idle Channel Impulse Noise Amplitude Histogram

BER = 4.4×10^{-5}

Figure A2-18c

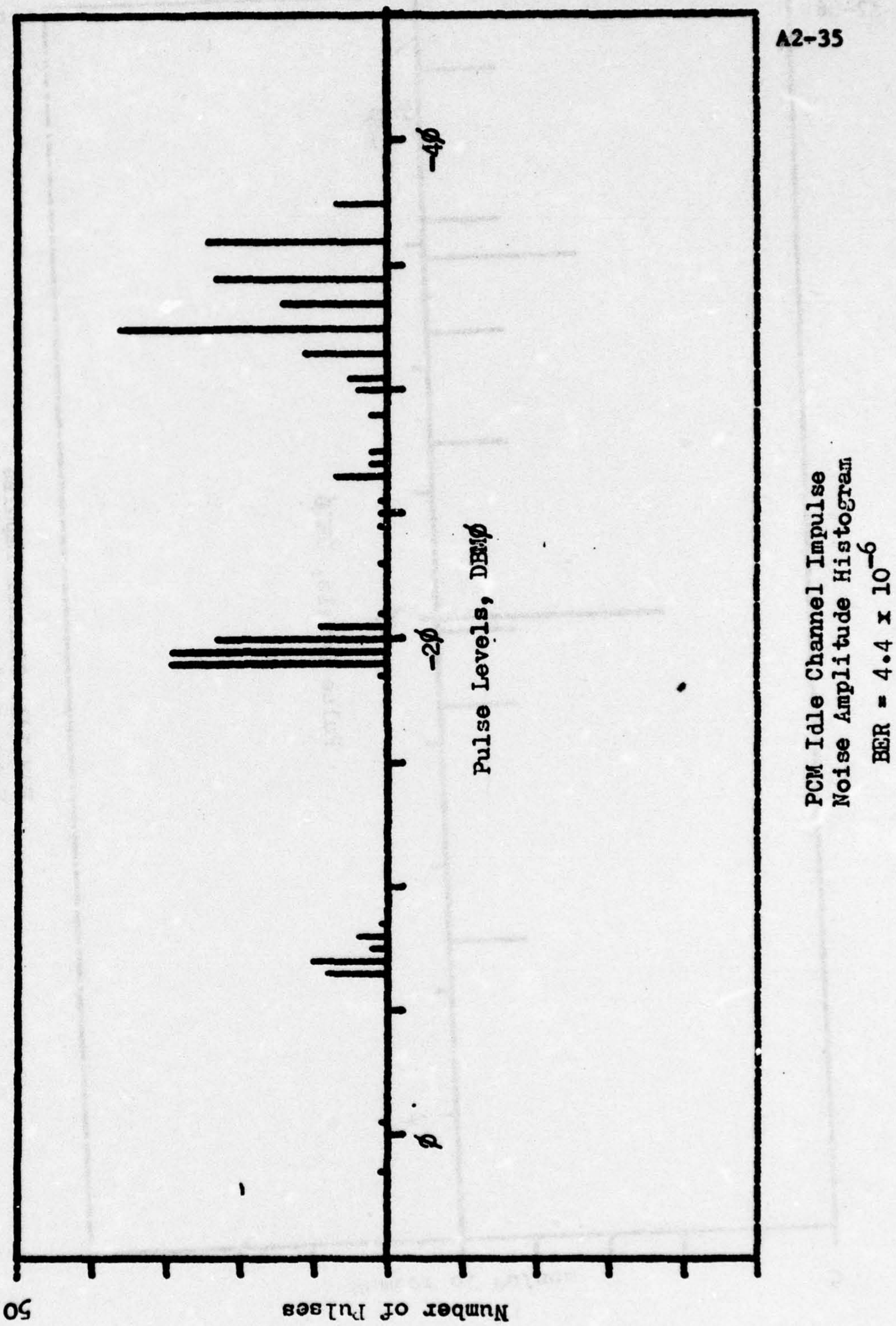


Figure A2-18d

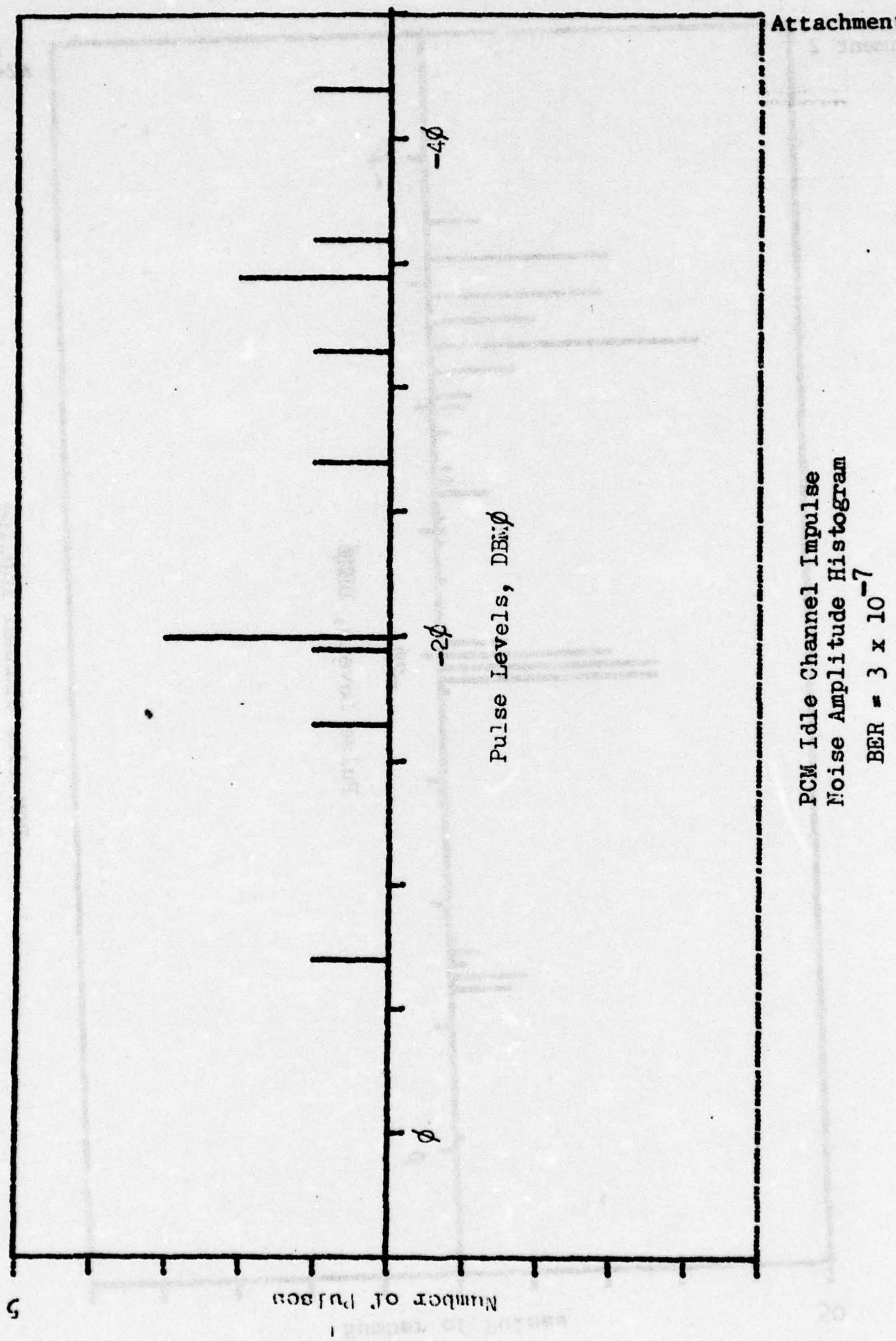


Figure A2-18e

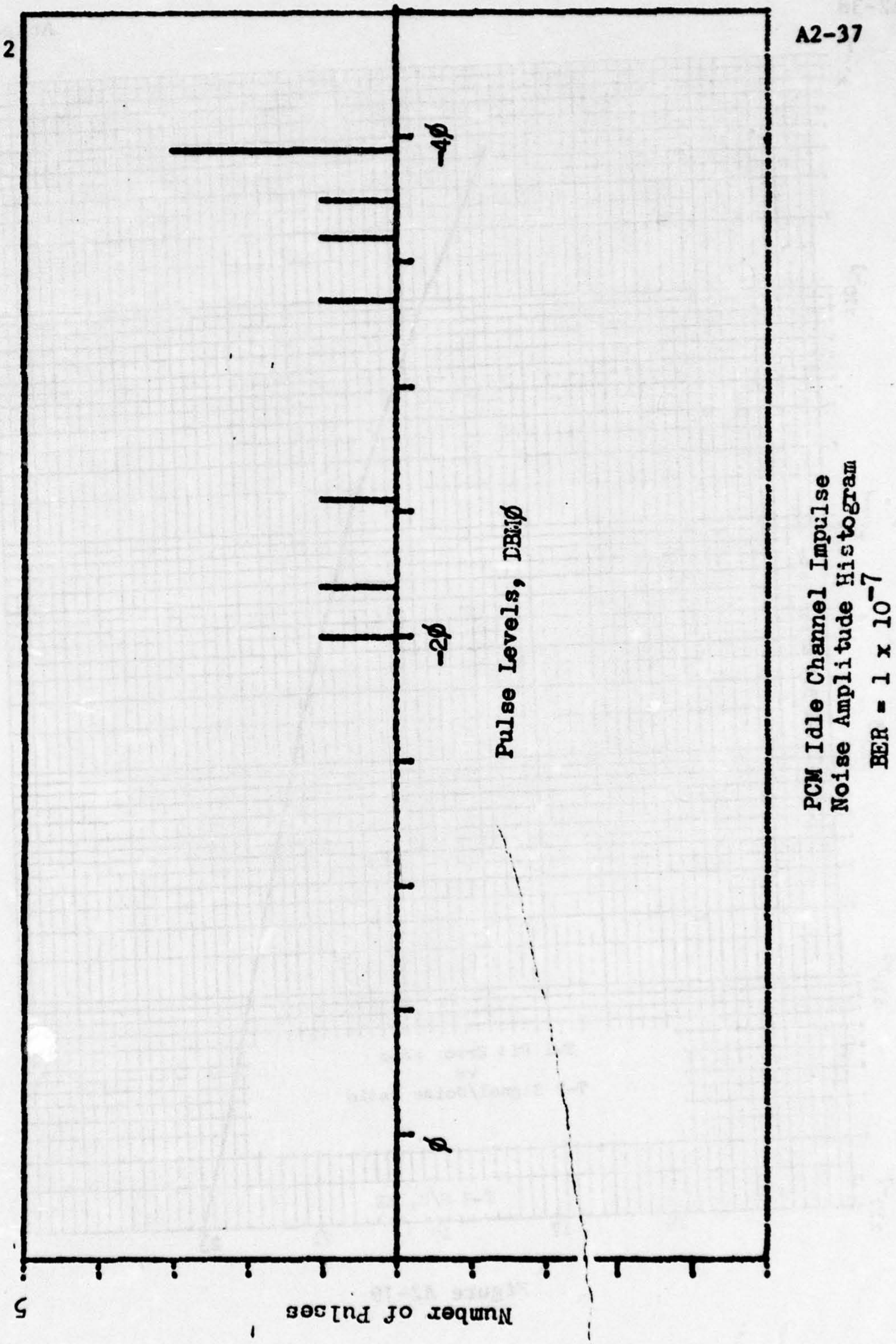


Figure A2-18f

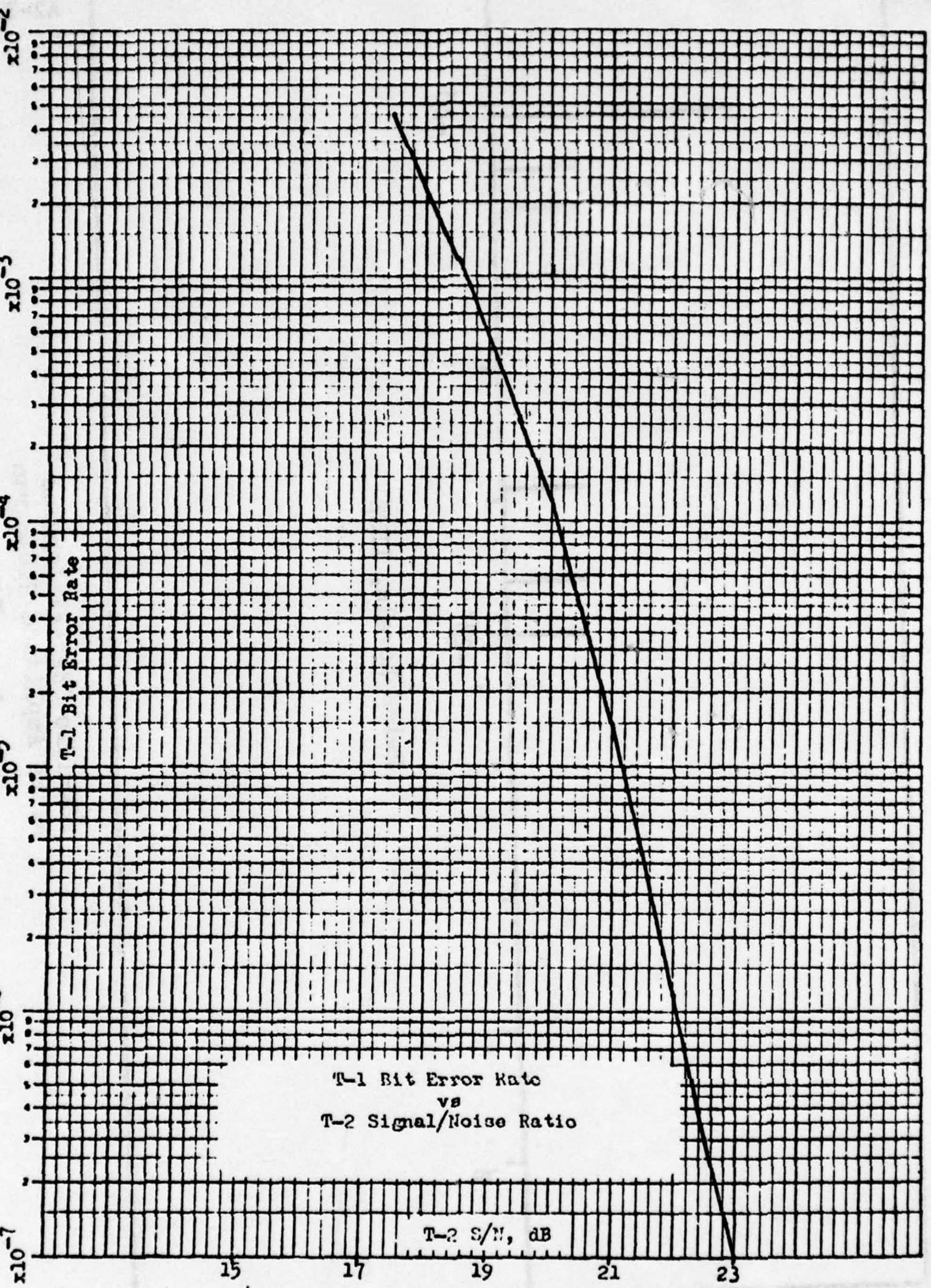

x10^-2
x10^-3
x10^-4
x10^-5
x10^-6
x10^-7
T-1 Bit Error Rate
T-1 Bit Error Rate
vs
T-2 Signal/Noise Ratio
T-2 S/N, dB
15
17
19
21
23

Figure A2-19

OVERHEAD CHANNEL INVESTIGATION

3-1. Test Objectives. The primary objective of overhead channel testing was to investigate the performance of an overhead channel inserted above the TDM baseband spectrum and to determine the effects of the presence of an overhead channel and filters on the TDM signal.

3-2. Discussion. In evaluating the overhead channel performance, two approaches were taken:

a. The first approach dealt with the direct and indirect effects of the TDM signal on the overhead channel performance. This approach was designed to be independent of specific equipment by relating overhead channel performance specifically to overhead carrier-to-noise ratio (C/N) in a 200 KHz slot at the frequency of the channel carrier under study.

b. The second approach dealt conversely with the overhead channel filter effects on the TDM data signal. Qualitative determination of TDM signal quality was made for each filter by observing, on an oscilloscope, the signal distortion introduced in the TDM eye pattern and by recording the extent of signal distortion indicated by the degradation monitor. Using the degradation monitors,

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TEST ENGINEERS: Capt George D. Peterson; Mr. David A. Lindberg

sample comparison was made also with and without the 7.5 MHz notch filter, showing the effects of signal distortion under decreasing microwave radio modulation index.

c. Each approach and related tests were designed to determine how well each filter met the requirements of RF bandwidth occupancy (for example, 99% of the radiated power must lie within the upper and lower bandwidth limits), least TDM distortion, and minimum overhead idle channel noise.

3-3. Test Procedures:

a. Baseline Equipment and Filter Characteristics. The procedures used to establish baseline equipment performance, verify operation of the MR-300 microwave radio employed in these tests and determine the characteristics of the overhead test filters are outlined below. The equipment was set up as shown in Figure A3-1, using the 7.5 MHz notch filter in the test filter position.

(1) *Verification of MR-300 Peak Deviation:*

(a) A 1.305 MHz test tone (1.0 Vp-p) was injected into the radio in place of the normal TDM signal (Figure A3-1).

(b) The MR-300 modulation amplifier gain control was adjusted for first carrier null as displayed on the spectrum analyzer, thus setting up the radio deviation for a modulation index of 0.5 (see paragraph (2)(b) *below* for detailed discussion of MR-300 deviation adjustment).

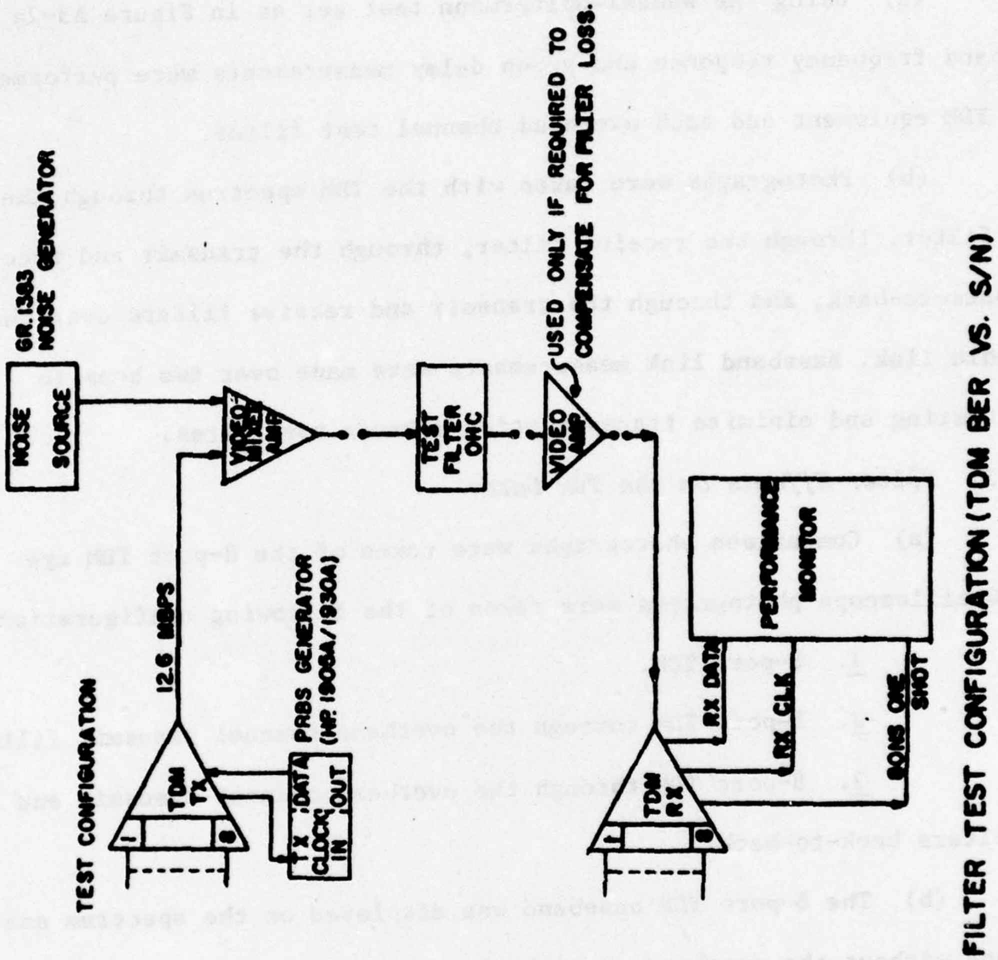

TEST CONFIGURATION
GR.1383 NOISE GENERATOR
NOISE SOURCE
VIDEO MIXER AMP
TEST FILTER OHC
VIDEO AMP
USED ONLY IF REQUIRED TO COMPENSATE FOR FILTER LOSS
12.6 MBPS
TDM TX
TX CLOCK IN
DATA OUT
PRBS GENERATOR (HP 1906A/1930A)
TDM RX
RX DATA
RX CLK
BCHS ONE SHOT
PERFORMANCE MONITOR
FILTER TEST CONFIGURATION (TDM BER VS. S/N)

Figure A3-1

(2) *Filter Characteristics:*

(a) Using the Wandel-Goltermann test set as in Figure A3-2a and 2b, baseband frequency response and group delay measurements were performed with the TDM equipment and each overhead channel test filter.

(b) Photographs were taken with the TDM spectrum through the transmit filter, through the receive filter, through the transmit and receive filters back-to-back, and through the transmit and receive filters over the MR-300 radio link. Baseband link measurements were made over two hops to simplify testing and minimize transportation between test sites.

(3) *Filter Effects on the TDM Data:*

(a) Comparison photographs were taken of the 8-port TDM eye pattern. Oscilloscope photographs were taken of the following configurations:

1. 8-port TDM.

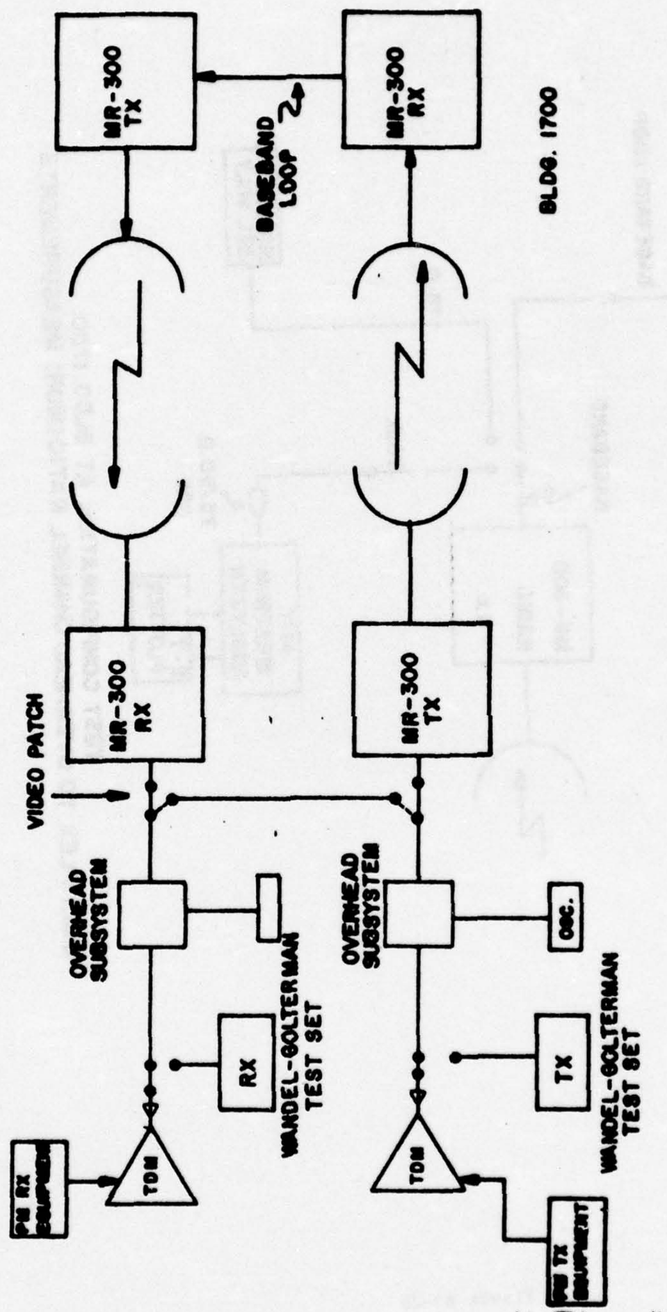
2. 8-port TDM through the overhead channel transmit filter.

3. 8-port TDM through the overhead channel transmit and receive filters back-to-back.

(b) The 8-port TDM baseband was displayed on the spectrum analyzer with and without the overhead channel filters. X-Y plots of this spectrum were also recorded.

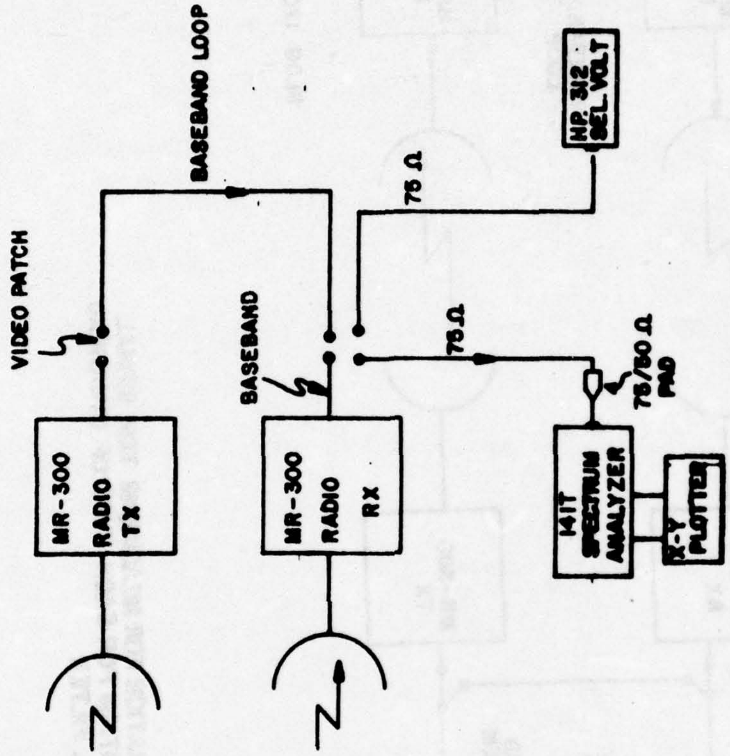
(c) To further determine the degrading effects of the overhead channel filters, BER vs TDM signal-to-noise ratio (S/N) measurements were taken using the performance monitoring equipment described in Attachment 2.

1. The test equipment was configured as shown in Figure A3-3.



CONFIGURATION FOR MEASURING TDM SIGNAL DEGRADATION FOR EACH TYPE OF OVERHEAD CHANNEL FILTER

Figure A3-2a



TEST CONFIGURATION AT BLDG. 1700.
MULTIPLEX TO OVERHEAD CHANNEL RATIO(MOR) MEASUREMENTS

Figure A3-2b

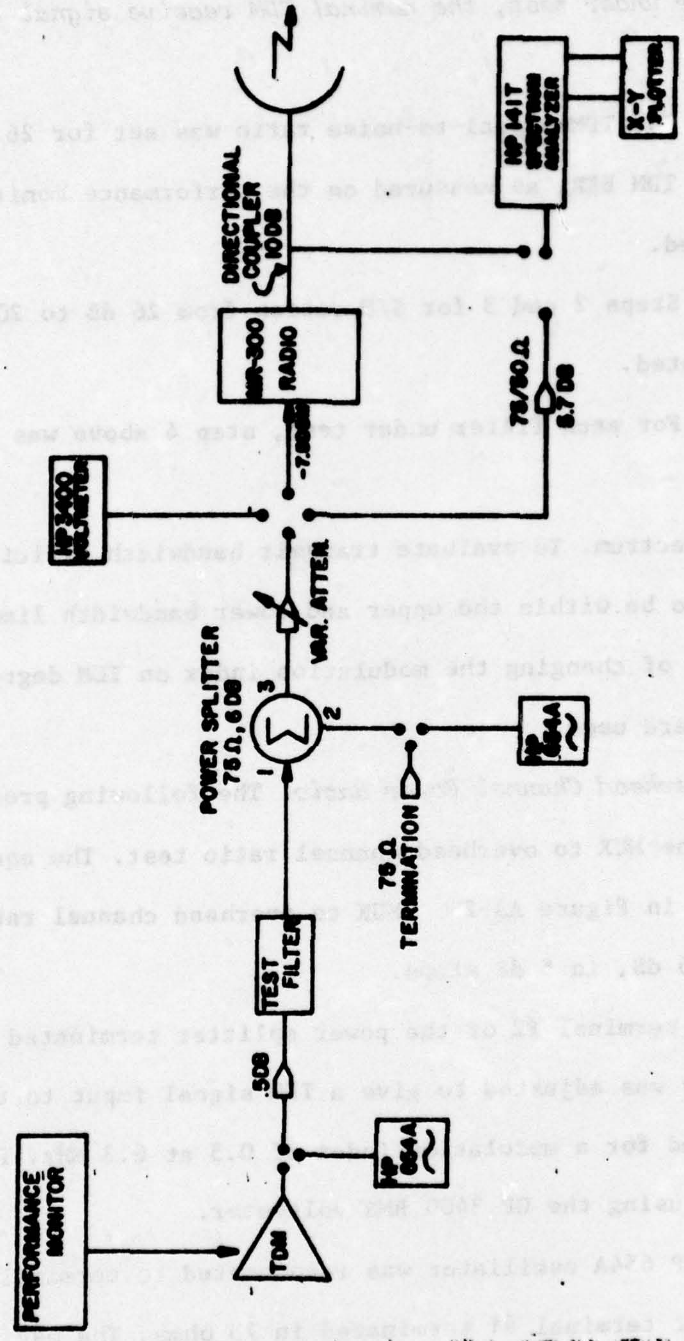

GENERAL TEST CONFIGURATION
BLDG 1202
PERFORMANCE MONITOR
TDM
HP 654A
TEST FILTER
75Ω TERMINATION
POWER SPLITTER
75Ω, 6 DB
VAR. ATTEN
HP3400 VOLTMETER
MR-300 RADIO
75/50Ω
5.7 DB
DIRECTIONAL COUPLER
10DB
HP 141T SPECTRUM ANALYZER
X-Y PLOTTER

Figure A3-3

NOTE: For each filter under test, the nominal TDM receive signal level was held at 1.0 Vp-p.)

2. The TDM signal-to-noise ratio was set for 26 dB.

3. TDM BER, as measured on the performance monitoring equipment, was then recorded.

4. Steps 2 and 3 for S/N ratios from 26 dB to 20 dB, in 1 dB steps, were repeated.

5. For each filter under test, step 4 above was repeated.

b. RF Transmit Spectrum. To evaluate transmit bandwidth efficiency (99% of occupied spectrum to be within the upper and lower bandwidth limits) and to examine the effects of changing the modulation index on TDM degradation, the procedures below were used.

(1) *TDM-to-Overhead Channel Power Ratio.* The following procedures were used to perform the MUX to overhead channel ratio test. The equipment configuration is shown in Figure A3-2b. MUX to overhead channel ratio were varied from 30 dB to -5 dB, in 5 dB steps.

(a) With terminal #2 of the power splitter terminated in 75 ohms, the variable attenuator was adjusted to give a TDM signal input to the radio of -7.5 dBm, as required for a modulation index of 0.5 at 6.3 MHz. Power measurements were made using the HP 3400 RMS voltmeter.

(b) The HP 654A oscillator was reconnected to terminal #2 of the power splitter and input terminal #1 terminated in 75 ohms. The oscillator

was then adjusted for a frequency of 7.5 MHz and for a power level of -7.5 dBm at the input to the radio.

(c) After reconnecting the TDM signal, the oscillator output was attenuated 30 dB thus giving a TDM-to-overhead channel ratio of 30 dB.

(d) RF transmit spectrum plots were taken for MUX to overhead channel ratio ranging from 30 dB to -5 dB in 5 dB steps. As a reference, spectrum plots were also taken without the overhead channel filters.

(e) The above procedure was repeated for each test filter and appropriate overhead channel frequency.

(2) *Modulation Index Testing.* The following procedures were used to investigate the effects of the RF transmit spectrum of changing the modulation index.

(a) Using the configuration of Figure A3-1 with no overhead channel filter, the modulation index was varied from 0.2 to 1.0. RF transmit spectrum plots were recorded for each modulation index. Comparison plots were also recorded showing the effects of introducing an overhead channel filter (7.5 MHz notch) in the TDM spectrum.

(b) Procedure for MR-300 FM deviation adjustment.

1. Since the modulation index, M, is given by

$$M = \frac{\Delta f}{f_m}$$

Where Δ f is the peak-to-peak deviation and f_m is the highest modulation frequency, then f = m f_m. The deviation is adjusted to produce the first carrier null of a test tone at the same amplitude as the modulation input

signal (1.0 Vp-p). The test tone modulation frequency, f_t is given by

Where the constant, 2.4048, produces the first Bessel zero (null condition).

Combining the above two equations:

$$f_t = \frac{m\ f_m}{2.4048}$$

For the 8-port TDM the highest modulating frequency f_m, is 6.276 MHz, therefore:

$$f_t = \frac{6.276}{2.4048}\ M = 2.6097xM\ (MHz)$$

2. The following table lists the modulation indexes used with the corresponding test frequencies and peak-to-peak deviations.

TABLE A3-1

Modulation Index	Test Frequency for Carrier Null	Peak-to-Peak Deviation
0.2	521.956 KHz	1.255 MHz
0.3	782.934 KHz	1.882 MHz
0.35	913.423 KHz	2.196 MHz
0.4	1.043912 MHz	2.510 MHz
0.45	1.174401 MHz	2.824 MHz
0.5	1.30489 MHz	3.138 MHz
0.6	1.565868 MHz	3.765 MHz
0.7	1.826846 MHz	4.393 MHz
0.9	2.348802 MHz	5.648 MHz
1.0	2.60978 MHz	6.276 MHz

3. The sine-wave generator was adjusted to produce an output of 1.0 Vp-p (.353 Vrms) into a 75 ohm load at a frequency of f_t. The modulation amplifier gain of the MR-300 was adjusted to give the various deviations. The RF transmit spectrum was displayed on a spectrum analyzer and the amplifier gain adjusted to produce the first carrier null. The test tone was then removed and the TDM output applied to the same point.

(3) *Filter Degradation vs RSL and Modulation Index.* To further determine the amount of degradation in TDM signal contributed by the overhead channel, the performance of the TDM system was monitored under varying receive signal levels for selected modulation indices. Reference measurements, under the same conditions, were made without the overhead channel filters.

(a) To monitor the degree of overhead channel degradation, the following procedures were used:

1. At Bldg 1700 (transmit site) the equipment was configured to adjust the modulation index as outlined in the previous procedures. Receive signal level was varied by attenuating the transmit output power using a variable waveguide attenuator.

2. At Bldg 1202 (receive site) the performance monitor was calibrated and set up to measure the degradation in TDM receive signal and the actual receive signal level.

3. For a given modulation index, the transmit output power was attenuated for minimum attenuation to a value which produced full-scale deflection of the degradation monitor at the receive site. This procedure was

performed both without an overhead channel filter and with a 7.5 MHz notch overhead channel filter.

4. The above procedures were performed for modulation indices of 0.5, 0.45, 0.40, 0.35 and 0.3.

5. At the receive site (Bldg 1202) the receive signal level and percent deflection of the degradation monitor were recorded for each test condition.

c. Noise Measurements. To charaterize the receive radio carrier-to-noise ratio (C/N) for various MUX to overhead channel ratio values, the following procedure was followed:

(1) Bldg 1202 was the transmit site, configured as shown in Figure A3-1. The transmitter was set for a modulation index of 0.5. The overhead channel was provided by the test filter. The unmodulated carrier was provided by the HP 654A oscillator.

(2) Bldg 1700 was the receive site, configured as shown in Figure A3-2b. Noise measurements, using the HP 312 frequency selective voltmeter, were made in a 200 KHz band around the carrier frequency in 20 KHz increments.

(3) Baseband spectrum plots were made at both the transmit and receive sites. At the transmit site, X-Y plots of the TDM baseband were made with the test filter and no carrier, and with the test filter and carrier (MUX to overhead channel ratio = 0). At the receive site, these plots were repeated. An additional plot of the receive system noise was made with the transmit TDM disconnected.

(4) For each MUX to overhead channel ratio, noise measurements as described in step 2 were recorded. The MUX to overhead channel ratio was varied from 0 to 30 dB.

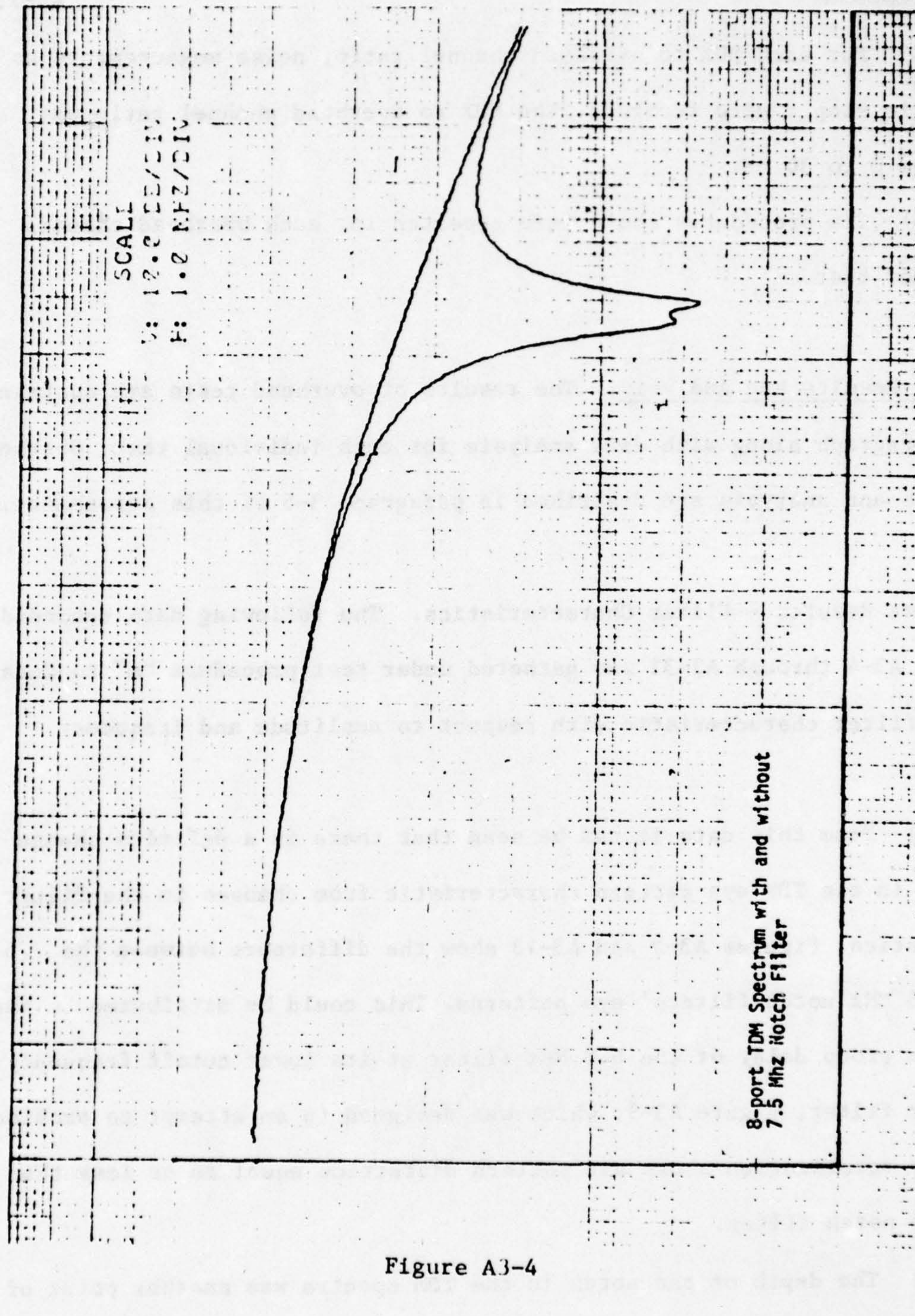
(5) The procedures above were repeated for each overhead channel filter under test.

3-4. Test Results and Analysis. The results of overhead tests are contained in this paragraph along with data analysis for each individual test. Overhead conclusions and analysis are described in paragraph 3-5 of this attachment.

a. Test Results - Filter Characteristics. The following data recorded in Figures A3-4 through A3-31 was gathered under test procedure "a" to determine each filter characteristic with respect to amplitude and frequency response.

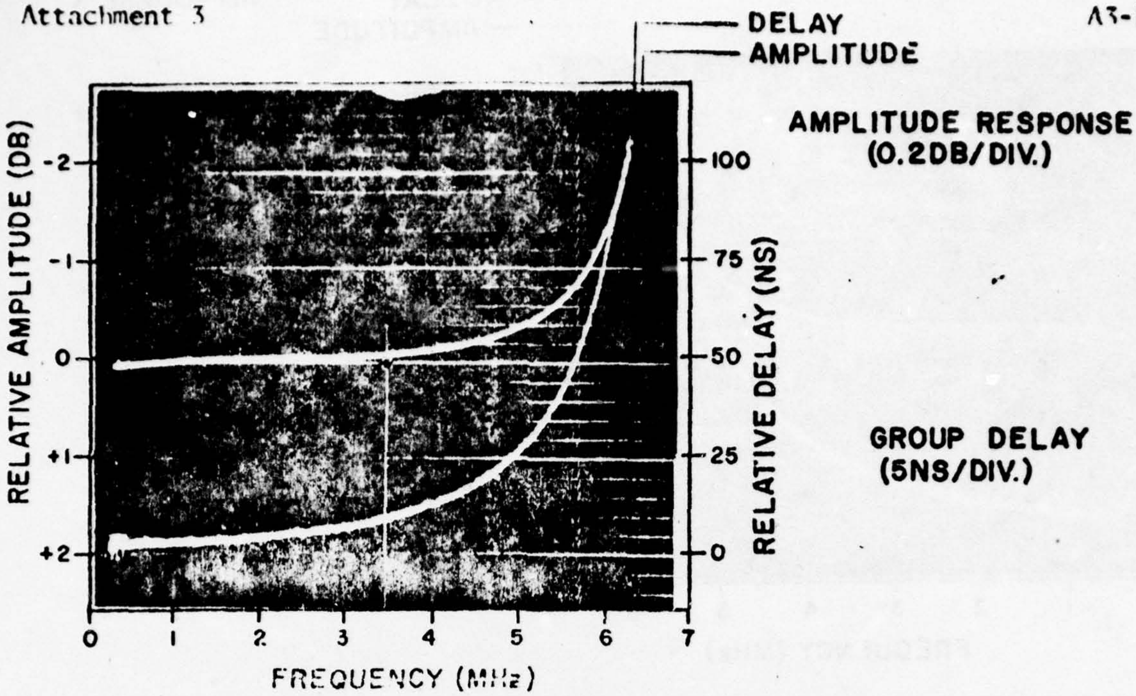
(1) From this data it can be seen that there is a definite change reflecting in the TDM eye pattern characteristic from changes in the filter characteristics. Figures A3-7 and A3-13 show the difference between the 7.5 MHz and 6.8 MHz notch filters' eye patterns. This could be attributed to the increase in group delay of the 6.8 MHz filter at its lower cutoff frequency. The 6.9 MHz filter, Figure A3-9, which was designed in an attempt to provide group delay equalization shows eye pattern distortion equal to or less than the 7.5 MHz notch filter.

(2) The depth of the notch in the TDM spectra was another point of

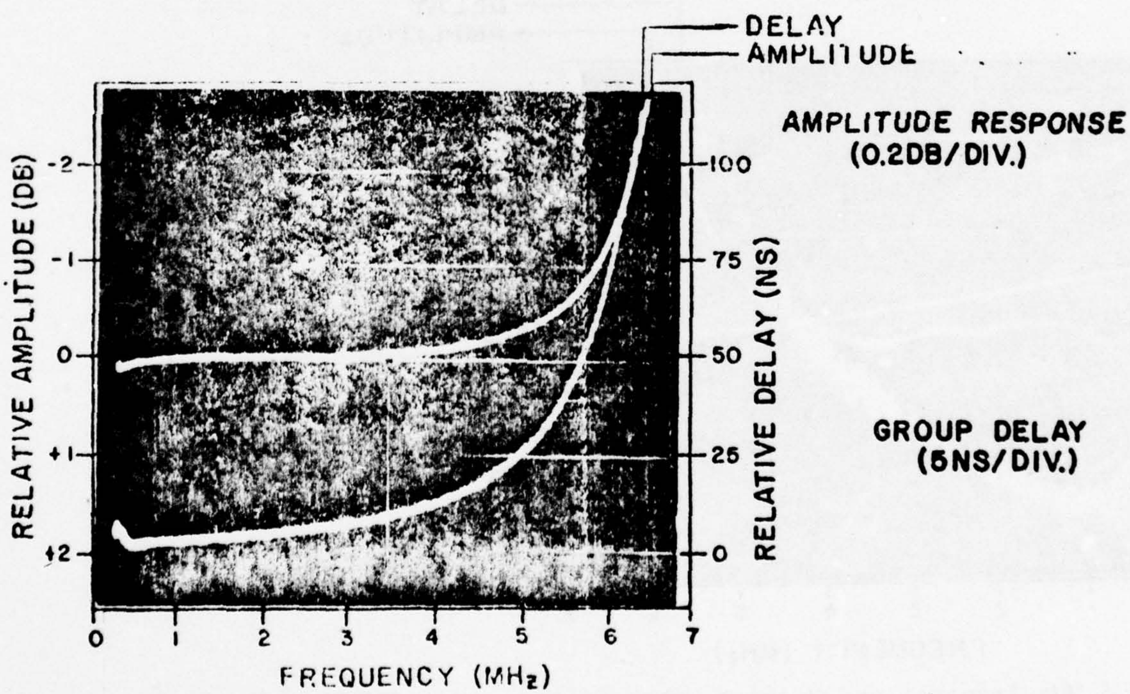


8-port TDM Spectrum with and without 7.5 Mhz Notch Filter

Figure A3-4

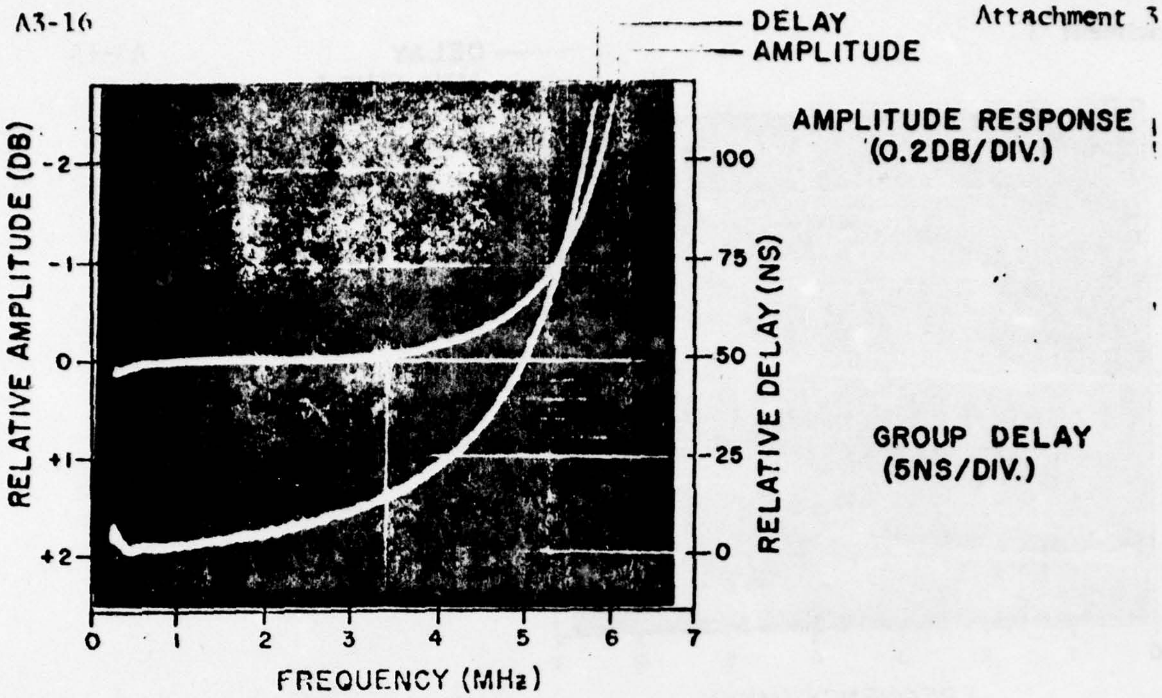


a) 7.5 MHz Transmit Notch Filter

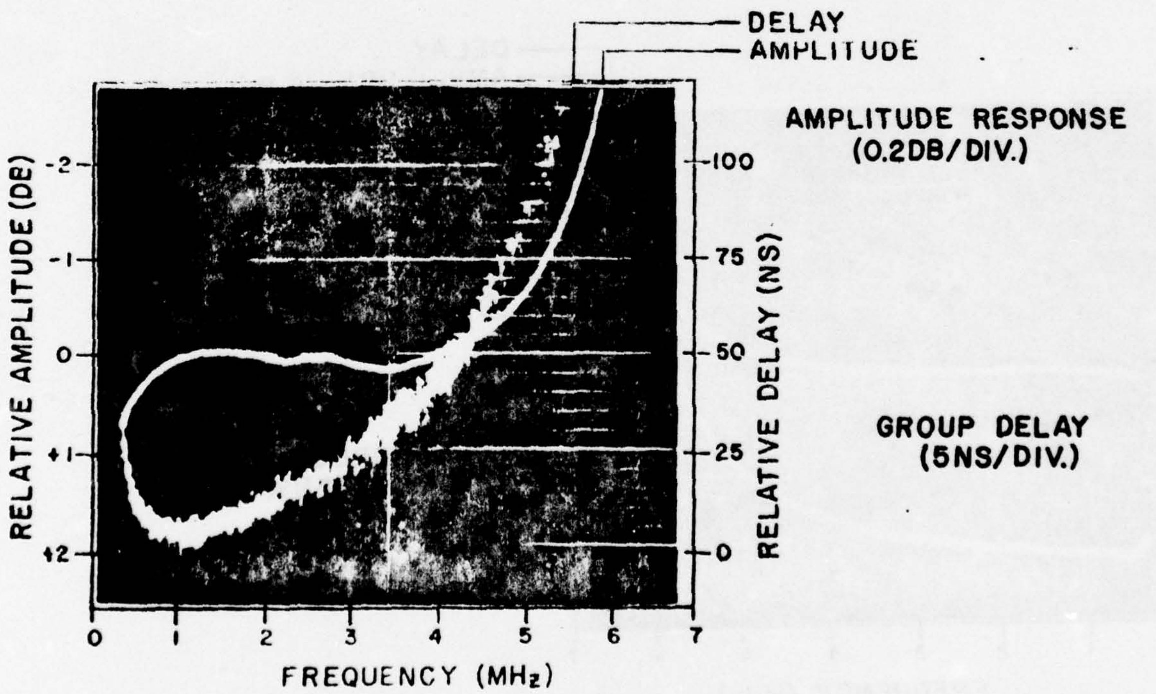


b) 7.5 MHz Receive Notch Filter

7.5 MHz Filter Characteristics
Figure A3-5

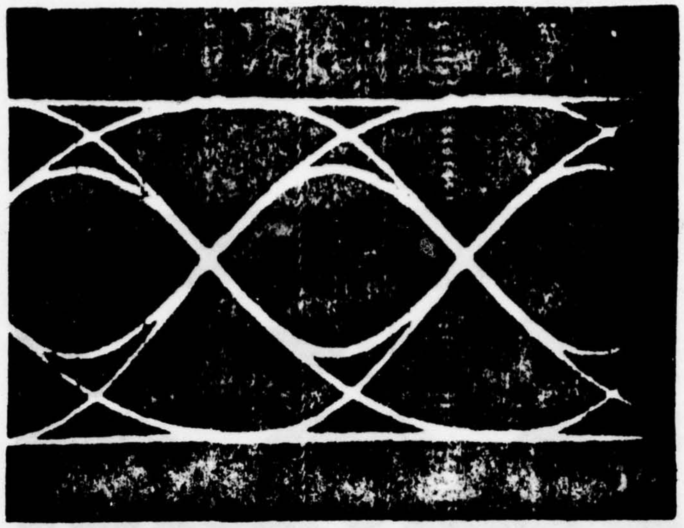


a) 7.5 MHz Transmit and Receive Notch Filter - back to back

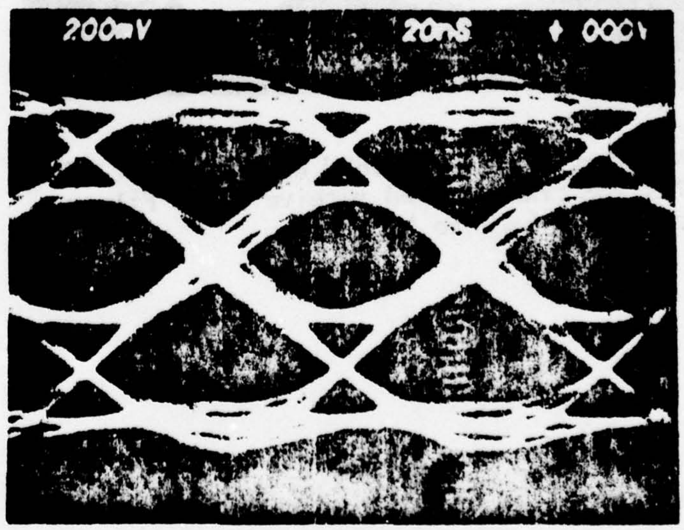


b) 7.5 MHz Transmit and Receive Notch Filter - over MR300 radio link

7.5 MHz Filter Characteristics
Figure A3-6

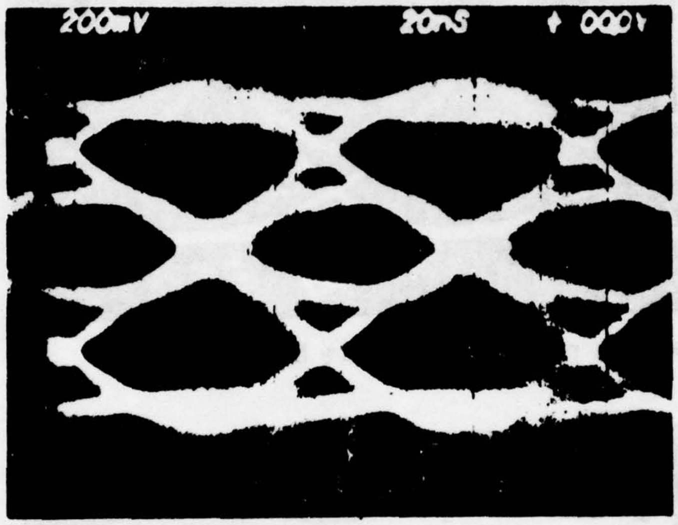


a) 8 - port TDM transmit EYE PATTERN



b) 8 - port TDM EYE PATTERN at the output of 7.5 MHz transmit NOTCH Filter

EYE PATTERN Distortion introduced by overhead channel filters
Figure A3-7



8 - port TDM EYE PATTERN at the output of 7.5 'Mz transmit and receive NOTCH Filter connected back to back

EYE PATTERN Distortion introduced by overhead channel filters
Figure A3-8

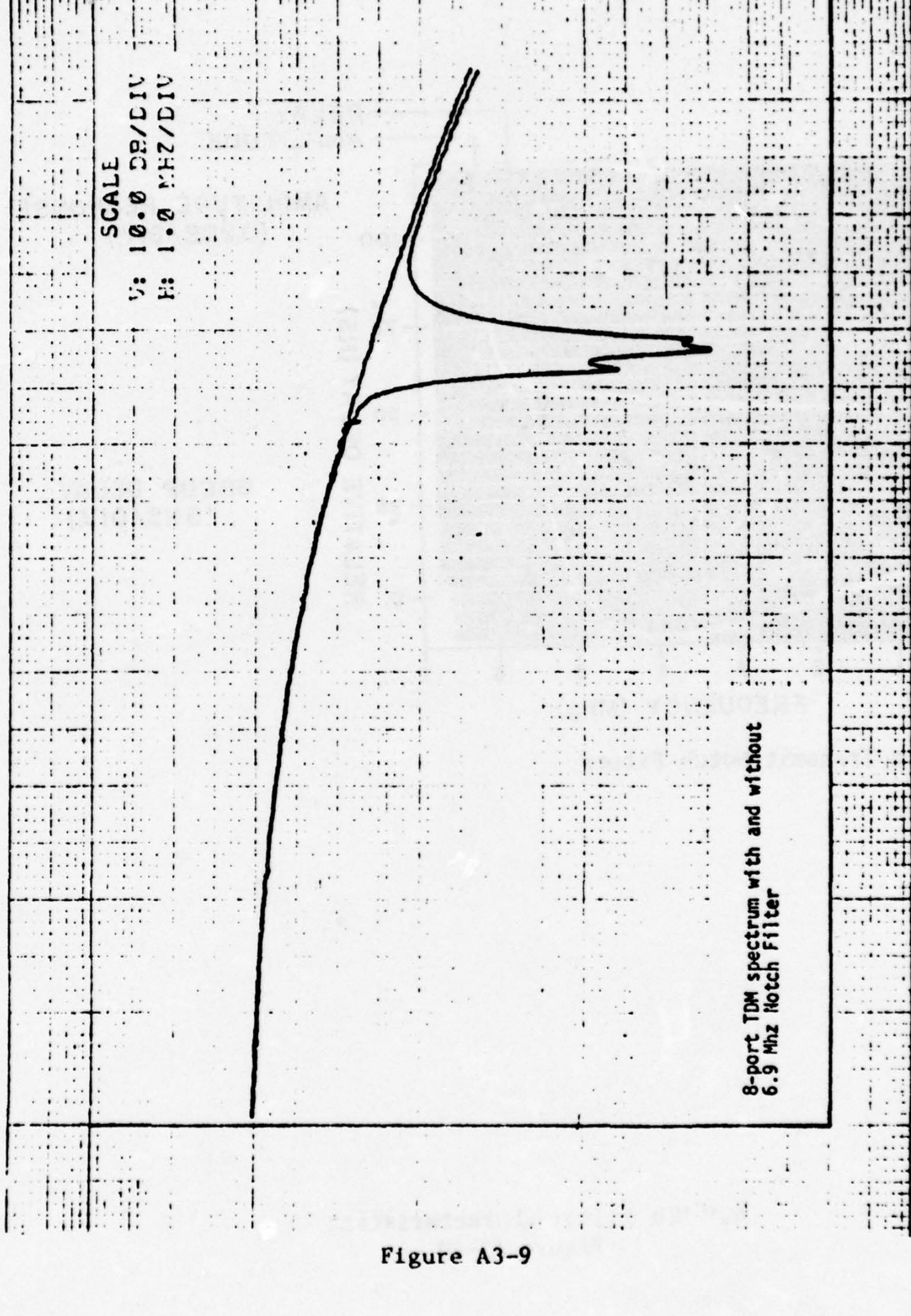
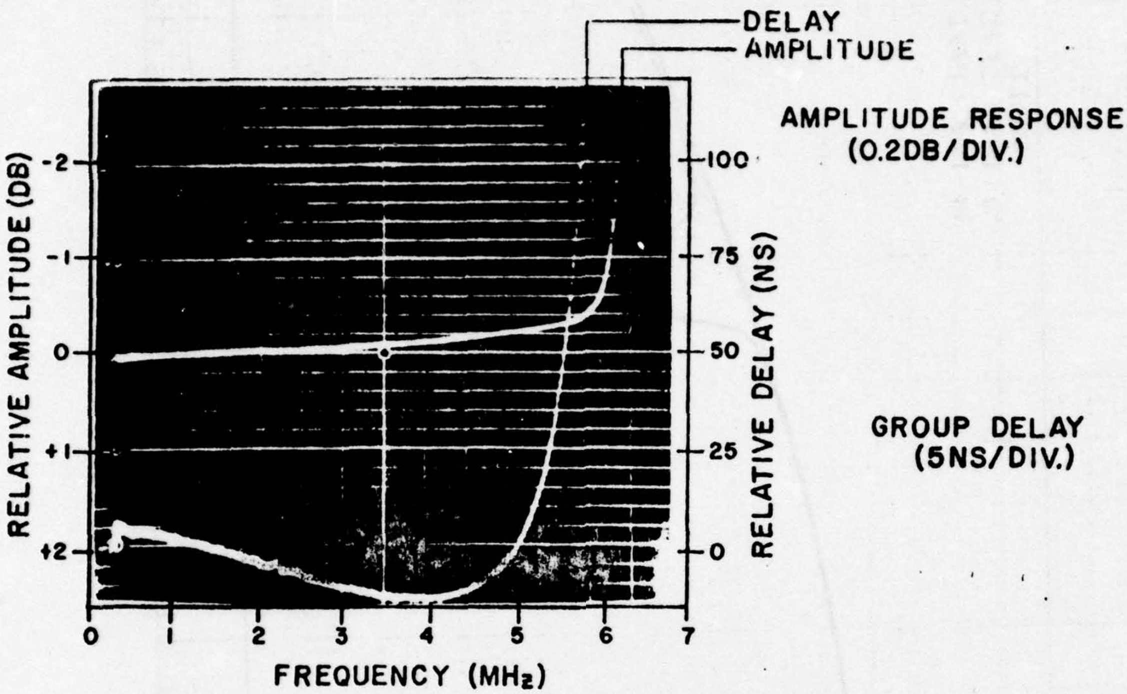
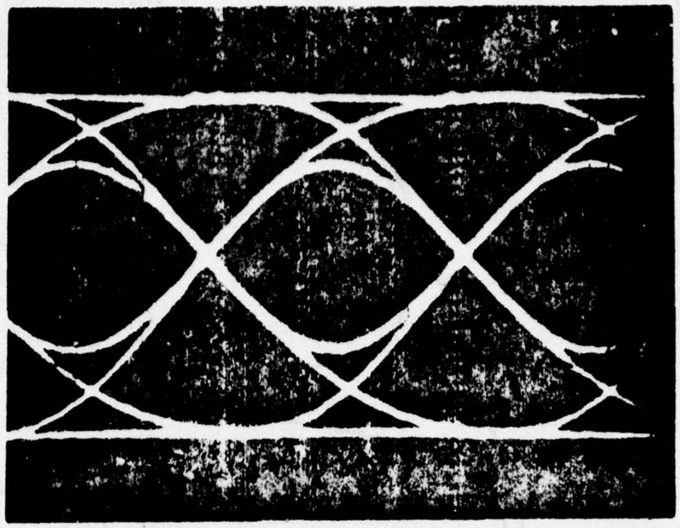

SCALE
V: 10.0 DB/DIV
H: 1.0 MHZ/DIV
8-port TDM spectrum with and without
6.9 Mhz Notch Filter

Figure A3-9

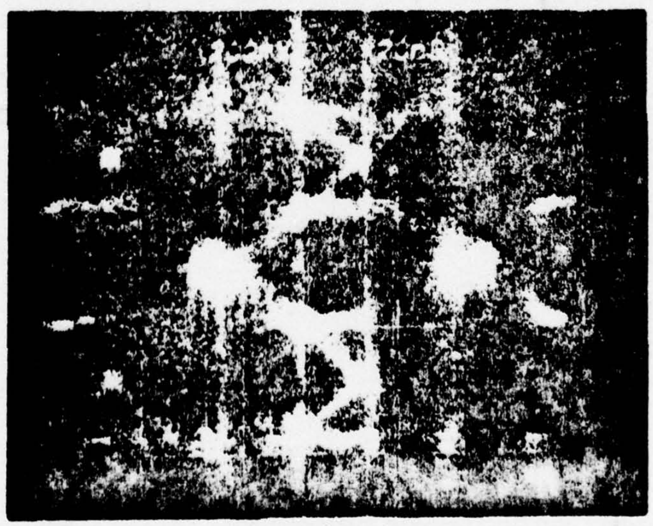


6.9 MHz Transmit Notch Filter

6.9 MHz Filter Characteristics
Figure A3-10



a) 8 - port TDM transmit EYE PATTERN



b) 8 - port TDM EYE PATTERN at the output of 6.9 MHz transmit NOTCH Filter

EYE PATTERN Distortion introduced by overhead channel filters

Figure A3-11

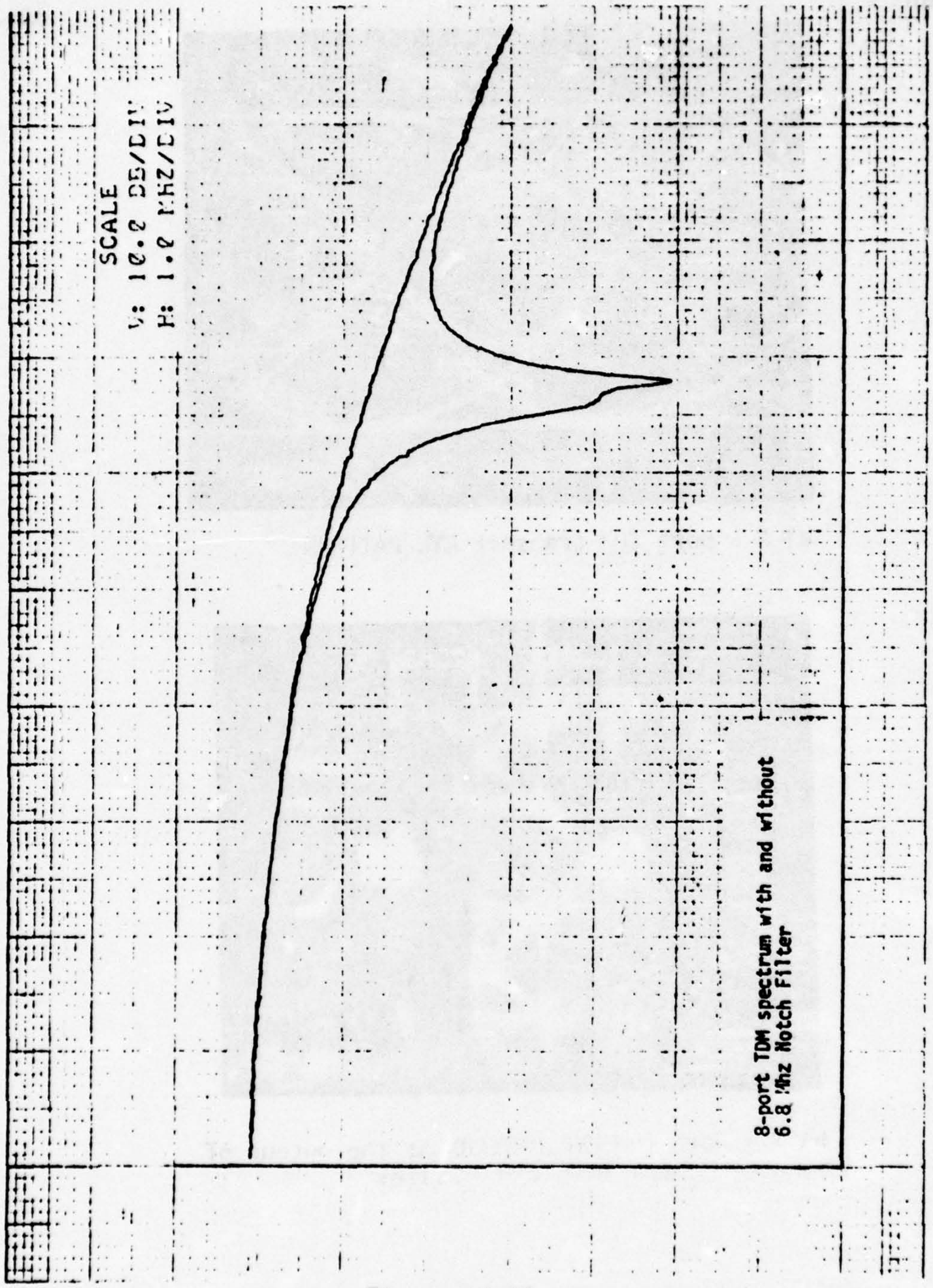
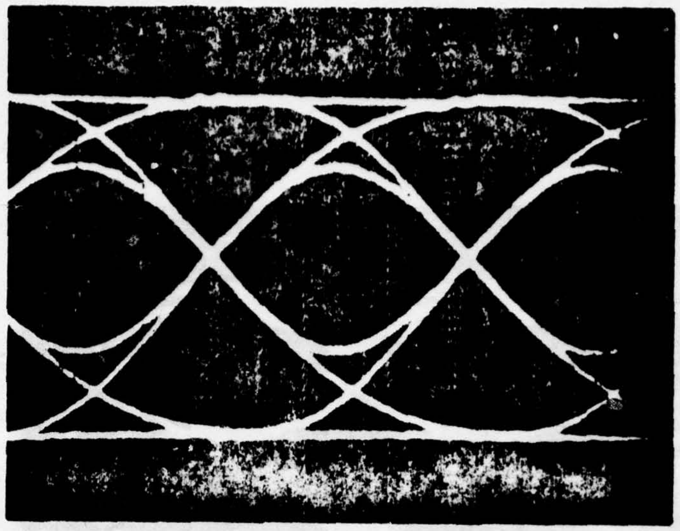
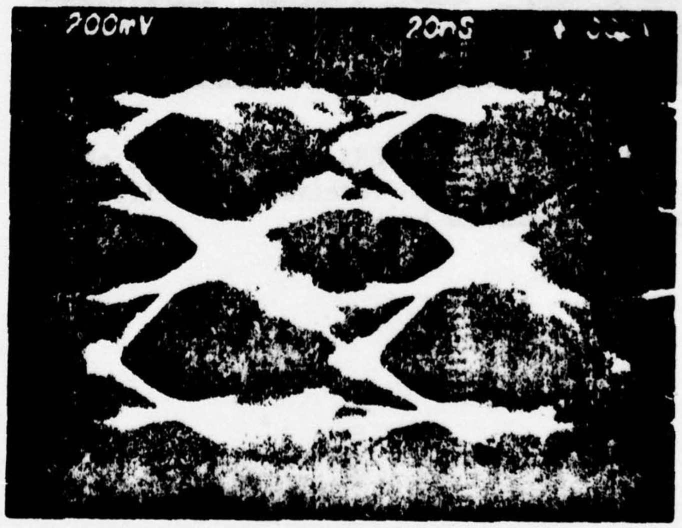

SCALE
V: 10.0 DB/DIV
H: 1.0 MHZ/DIV
8-port TDM spectrum with and without
6.8 Mhz Notch Filter

Figure A3-12

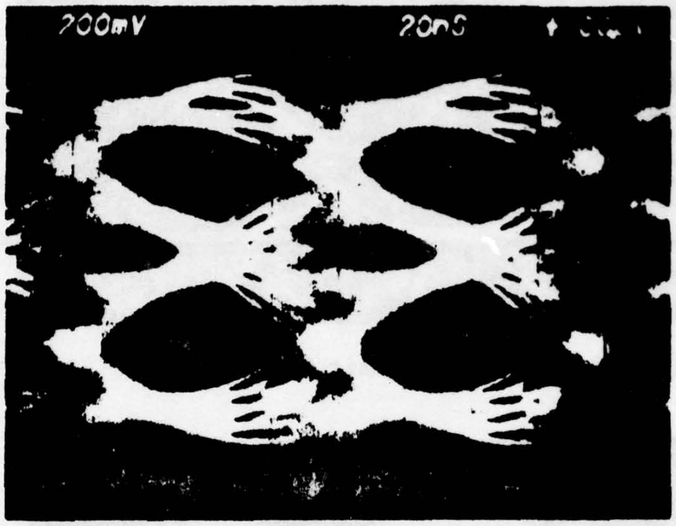


a) 8 - port TDM transmit EYE PATTERN



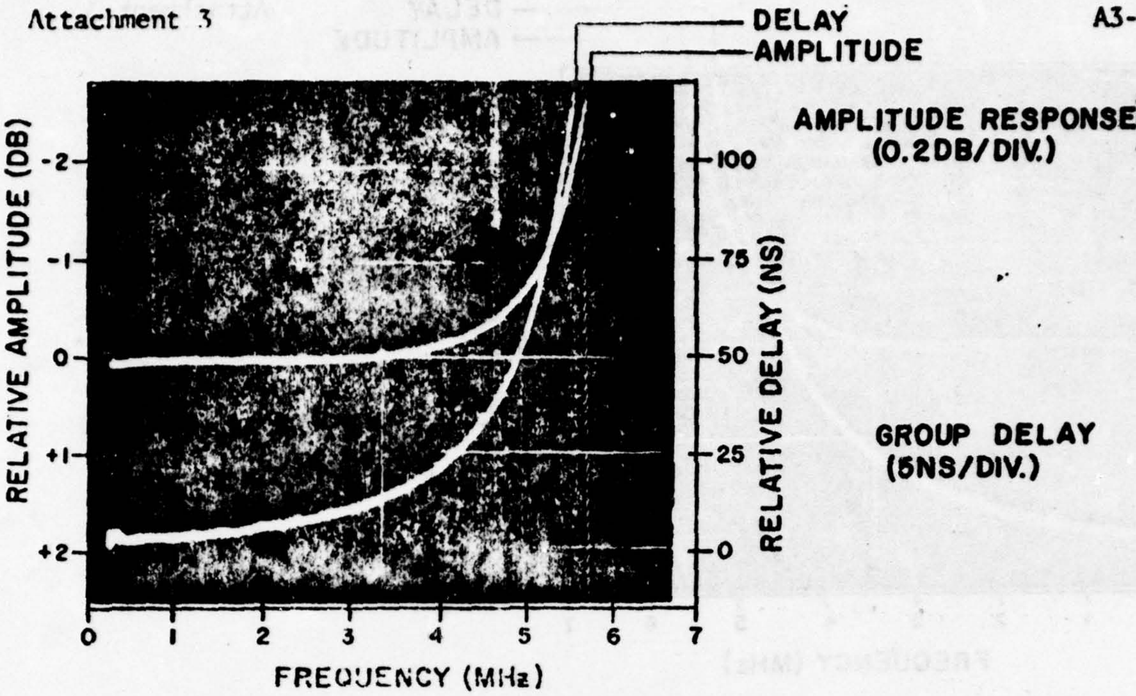
b) 8 - port TDM EYE PATTERN at the output of 6.8 MHz transmit NOTCH Filter

EYE PATTERN Distortion introduced by overhead channel filters
Figure A3-13

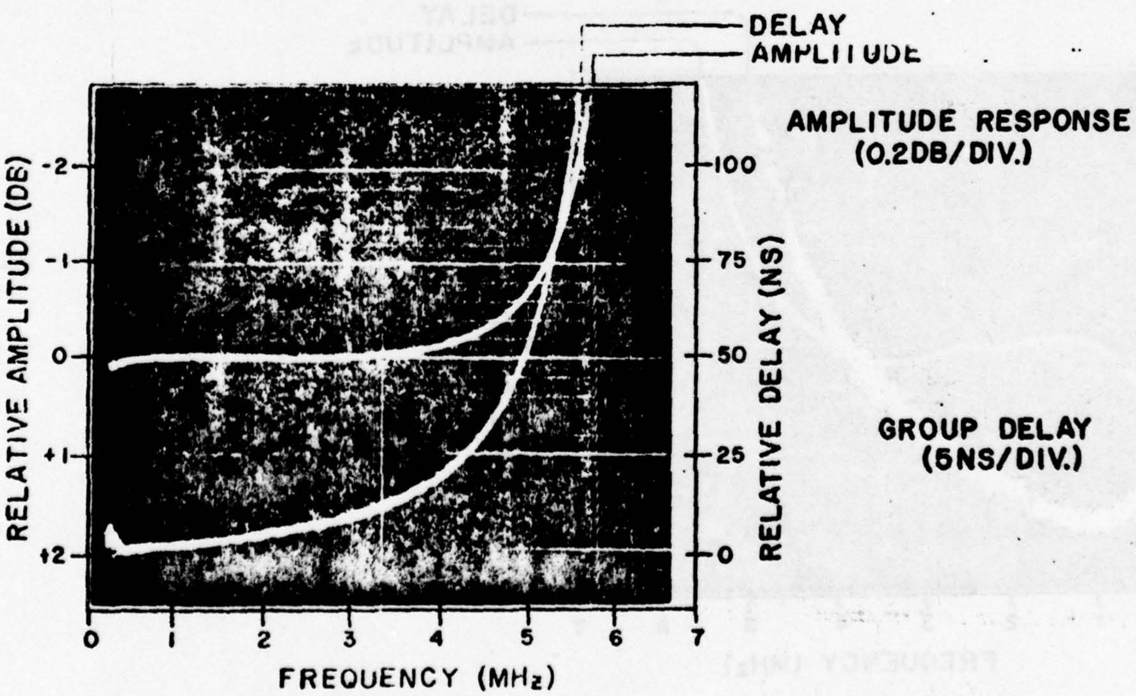


8 - port TDM EYE PATTERN at the output of 6.8 MHz transmit and receive NOTCH Filter connected back to back.

EYE PATTERN Distortion introduced by overhead channel filters
Figure A3-14

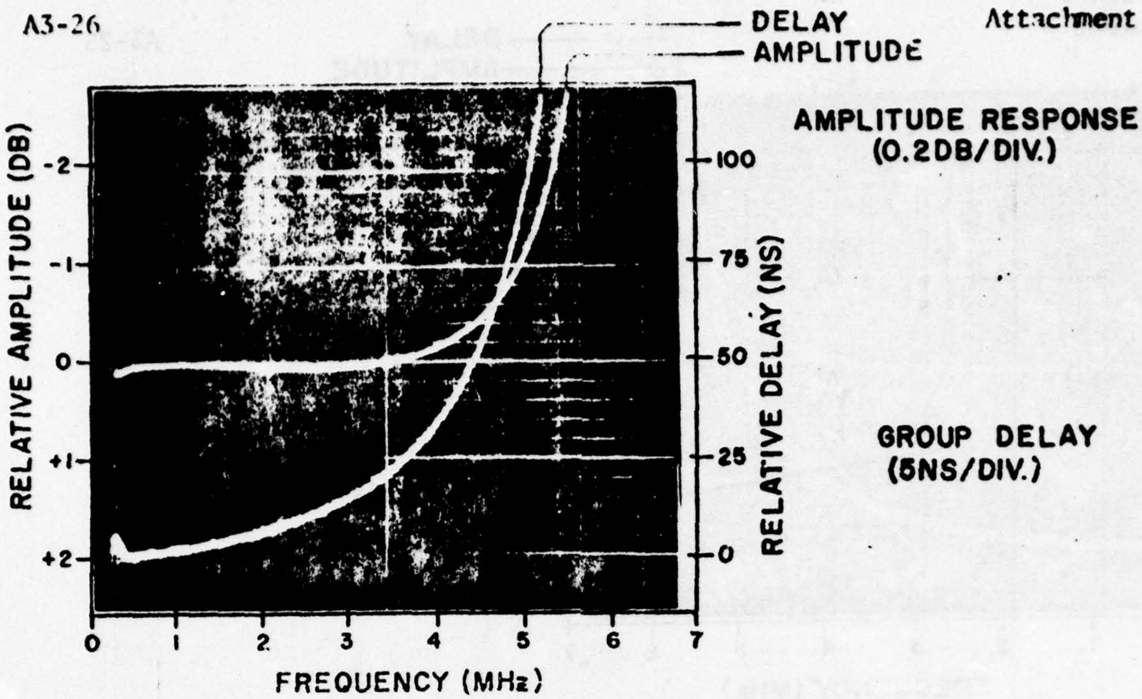


a) 6.8 MHz Transmit Notch Filter

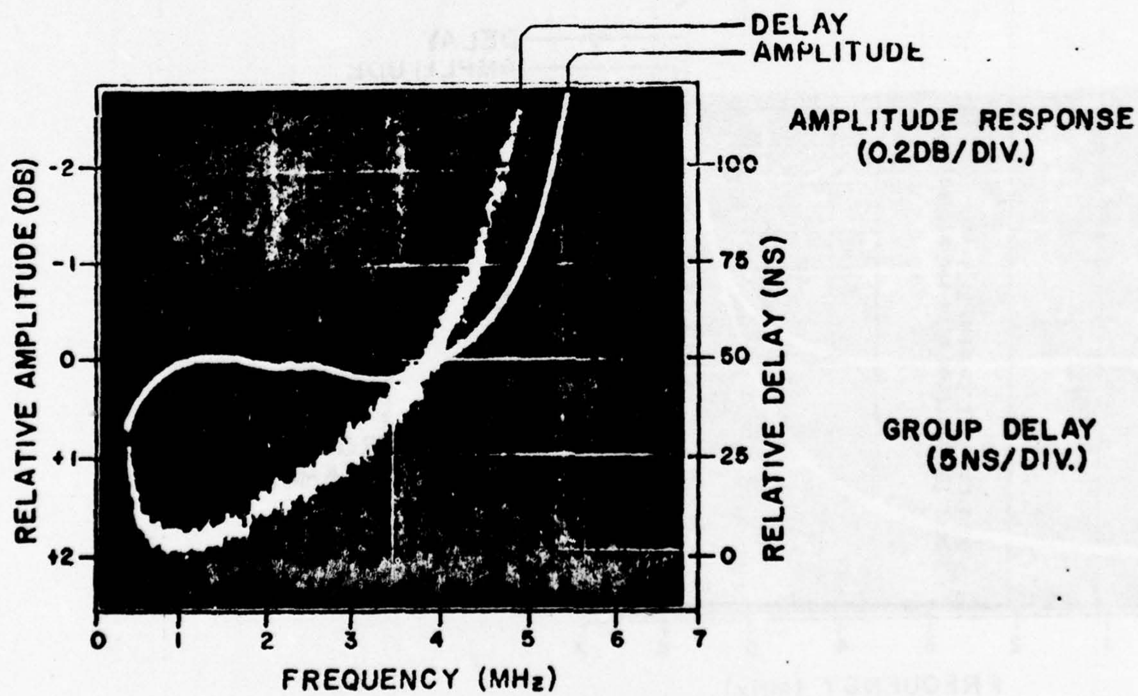


b) 6.8 MHz Receive Notch Filter

6.8 MHz Filter Characteristics
Figure A3-15



a) 6.8 MHz Transmit and Receive Notch Filter - back to back



b) 6.8 MHz Transmit and Receive Notch Filter - over MR300 radio link

6.8 MHz Filter Characteristics
Figure A3-16

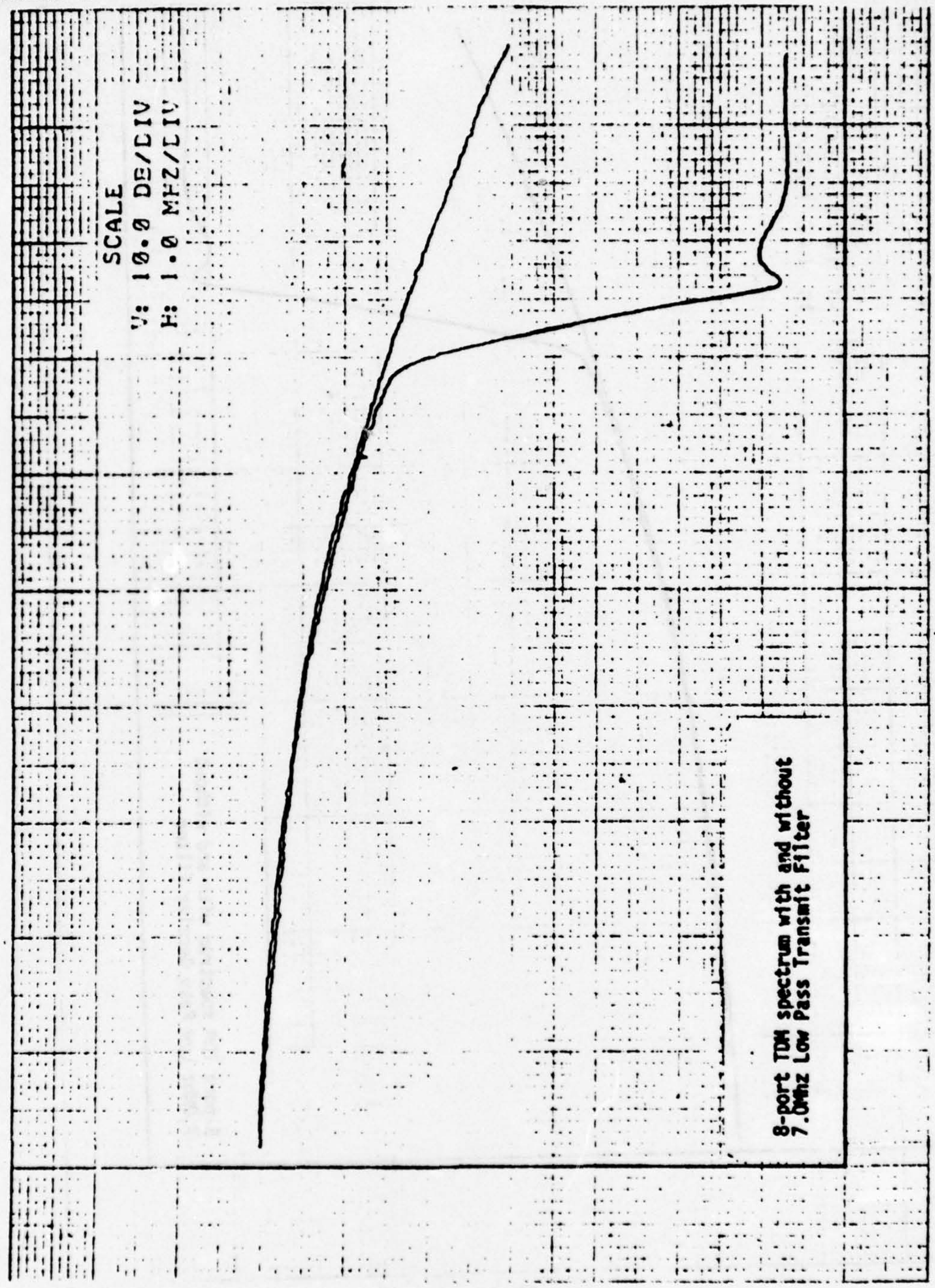

SCALE
V: 10.0 DB/DIV
H: 1.0 MHZ/DIV
8-port TDM spectrum with and without
7.0MHz Low Pass Transmit Filter

Figure A3-17

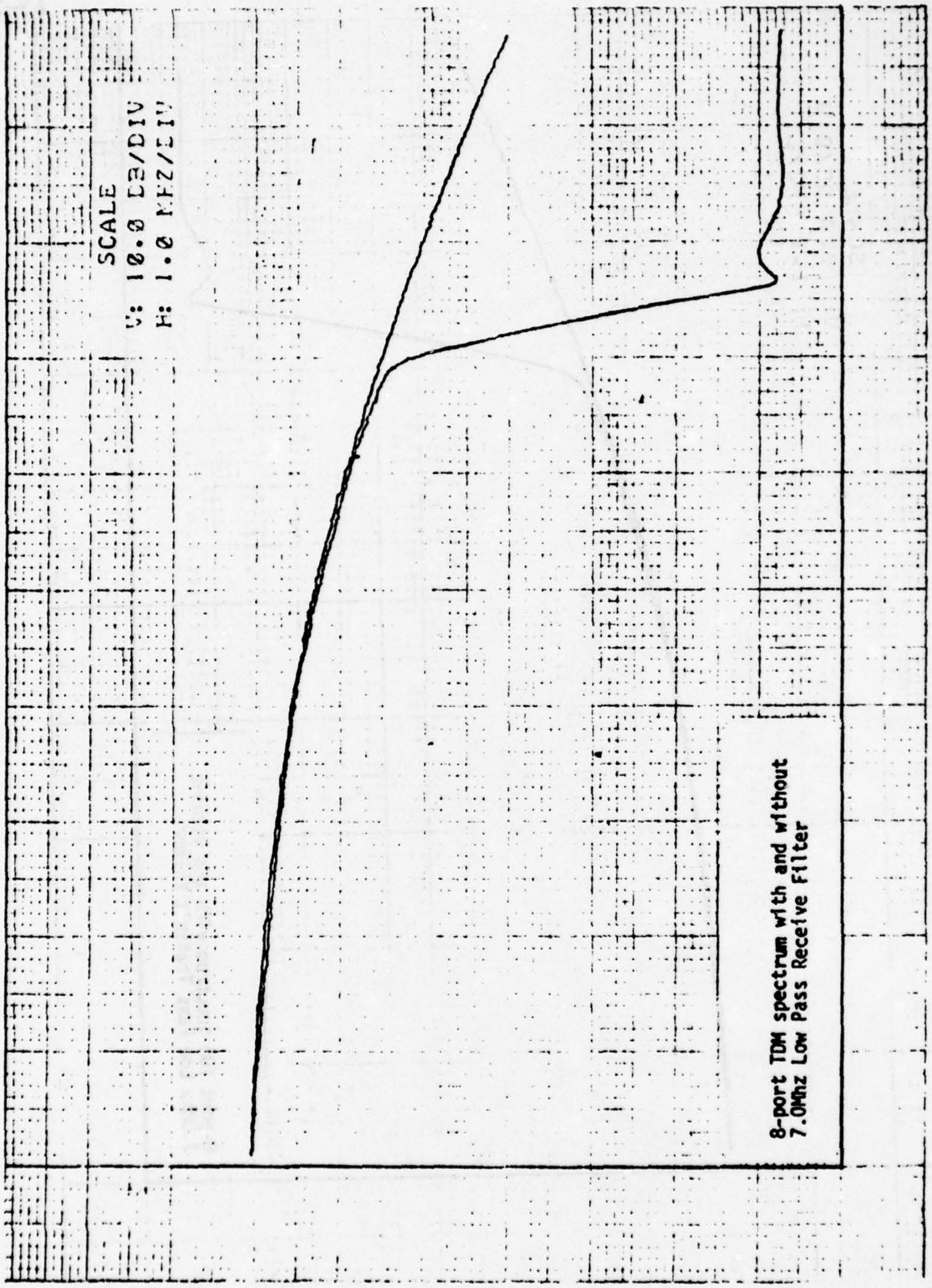
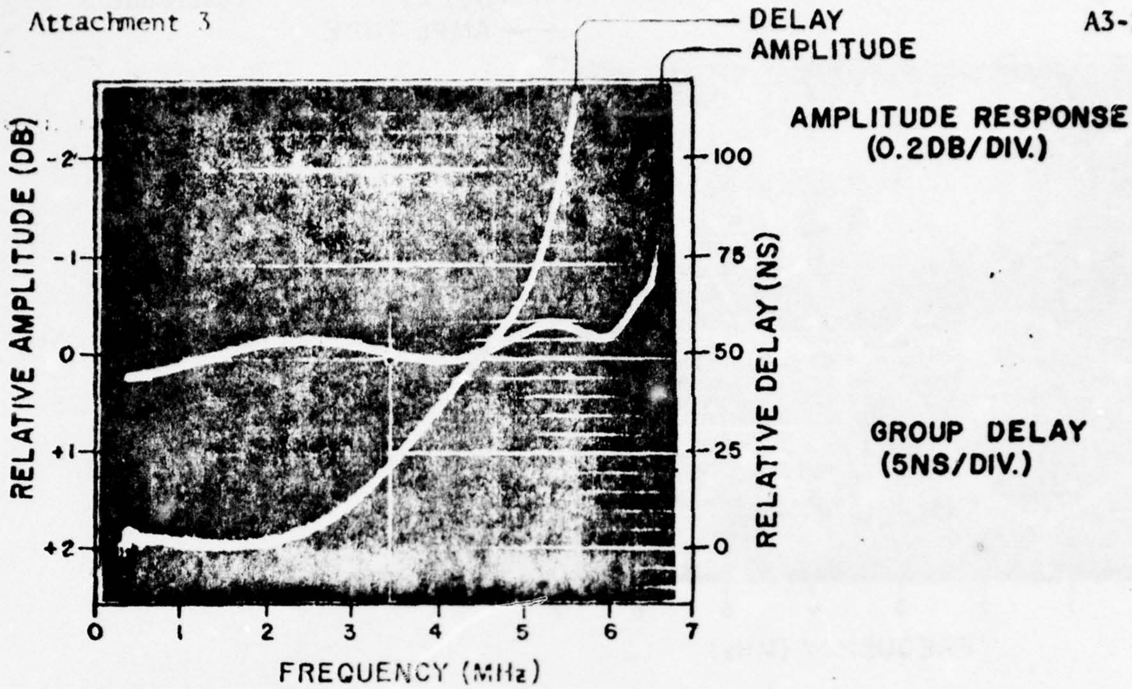
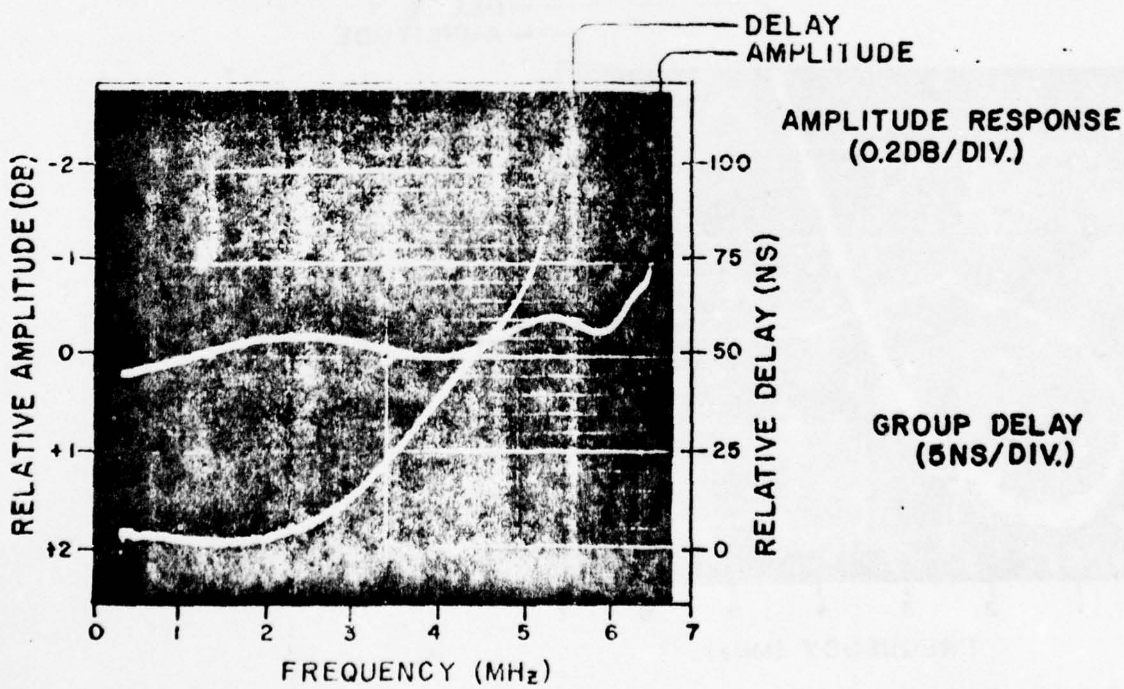

SCALE
V: 10.0 DB/DIV
H: 1.0 MHZ/DIV
8-port TDM spectrum with and without
7.0Mhz Low Pass Receive Filter

Figure A3-18

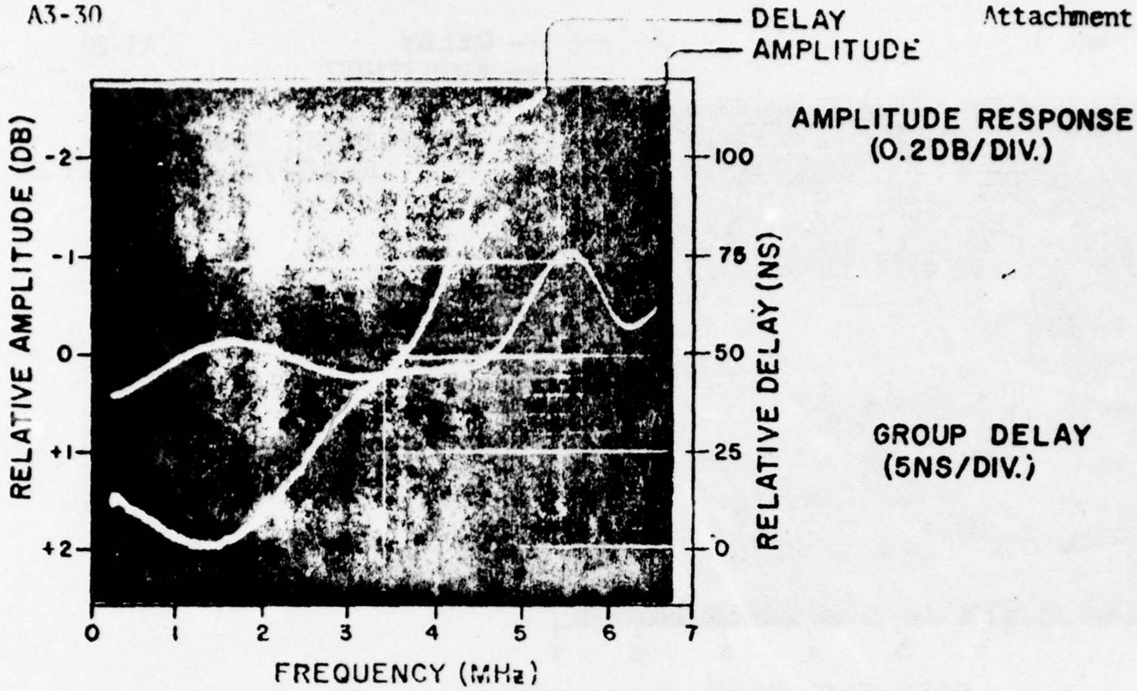


a) 7.0 MHz Transmit Low Pass Filter

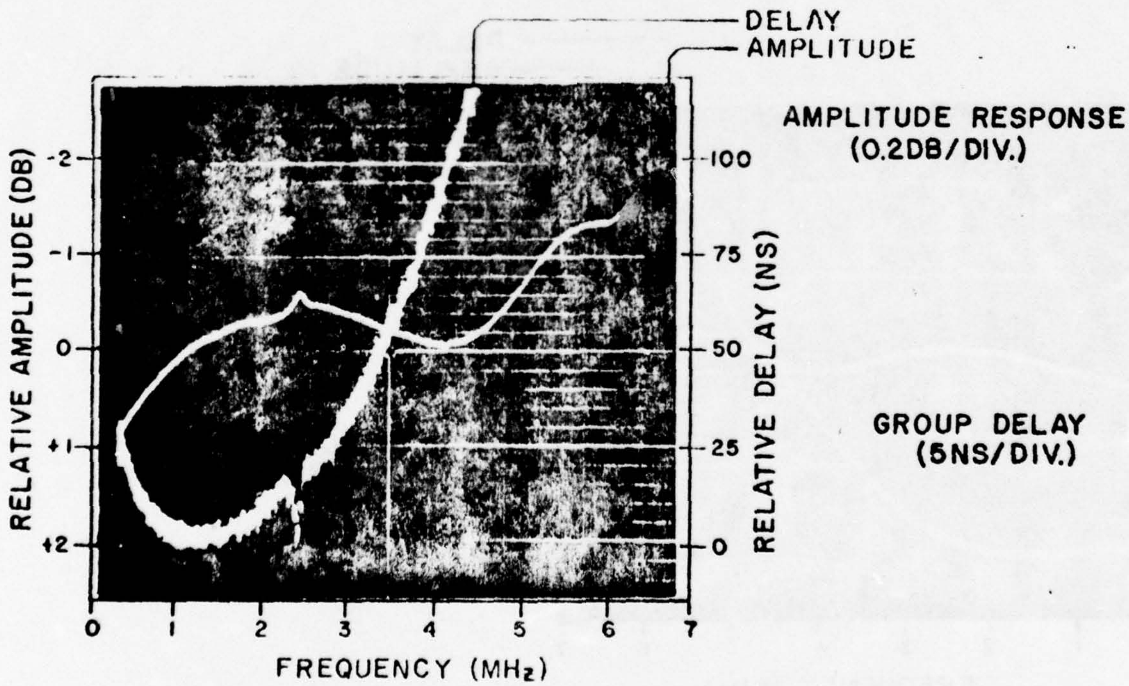


b) 7.0 MHz Receive Low Pass Filter

7.0 MHz Filter Characteristics
Figure A3-19

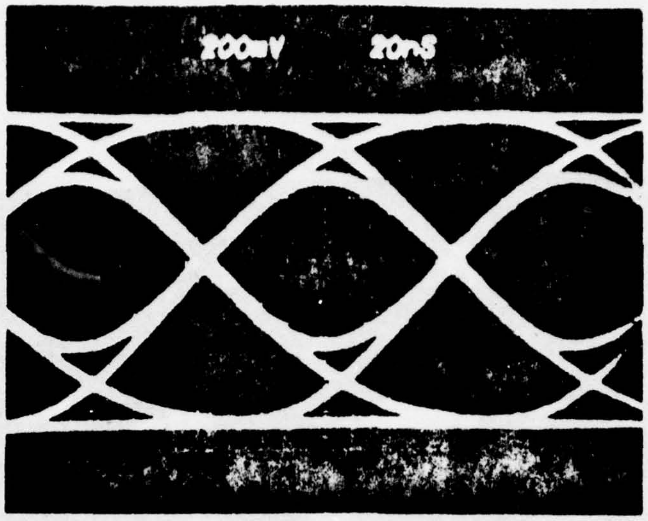


a) 7.0 MHz Transmit and Receive Low Pass Filter - back to back

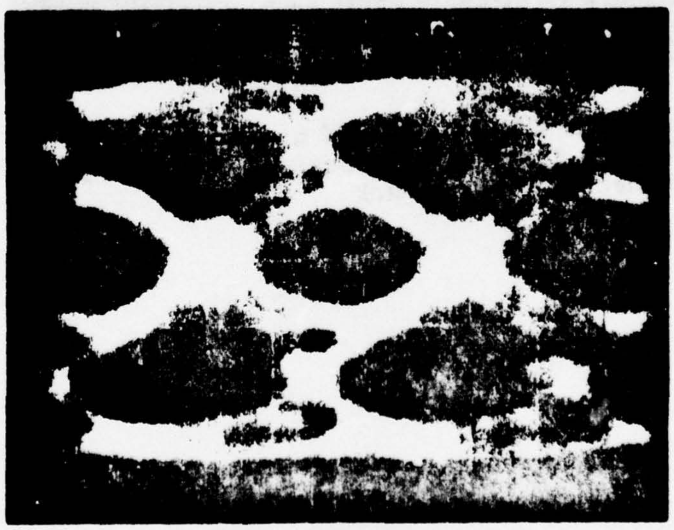


b) 7.0 MHz Transmit and Receive Low Pass Filter - over MR300 radio link

7.0 MHz Filter Characteristics
Figure A3-20



a) 8 - port TDM transmit EYE PATTERN



b) 8 - port TDM EYE PATTERN at the output of 7.0 MHz transmit LOW PASS Filter

EYE PATTERN Distortion introduced by overhead channel filters
Figure A3-21

8 - port TDM EYE PATTERN at the output of 7.0 MHz transmit and receive LOW PASS Filter connected back to back

EYE PATTERN Distortion introduced by overhead channel filters
Figure A3-22

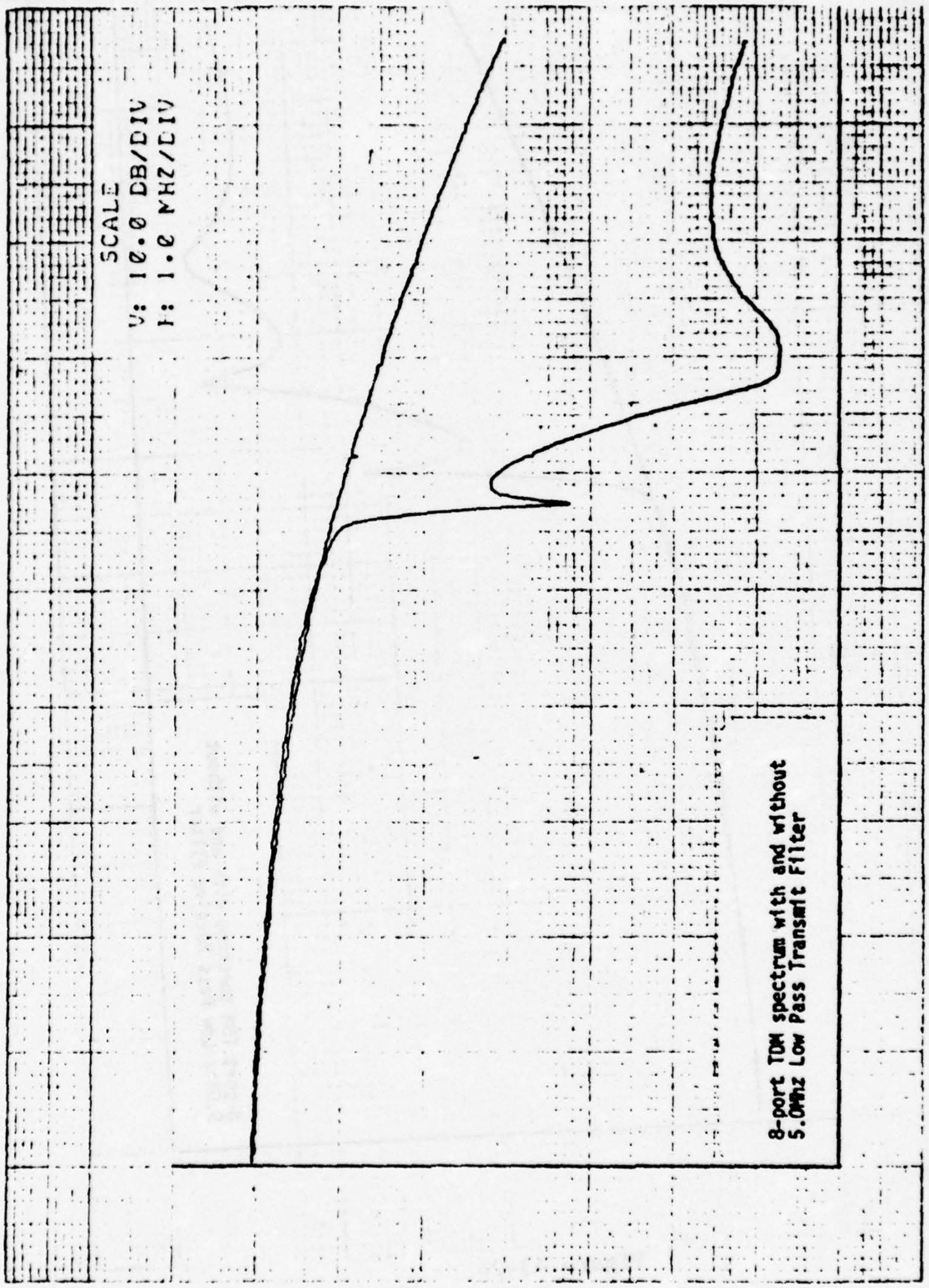

SCALE
V: 10.0 DB/DIV
H: 1.0 MHZ/DIV
8-port TDM spectrum with and without
5.0MHz Low Pass Transmit Filter

Figure A3-23

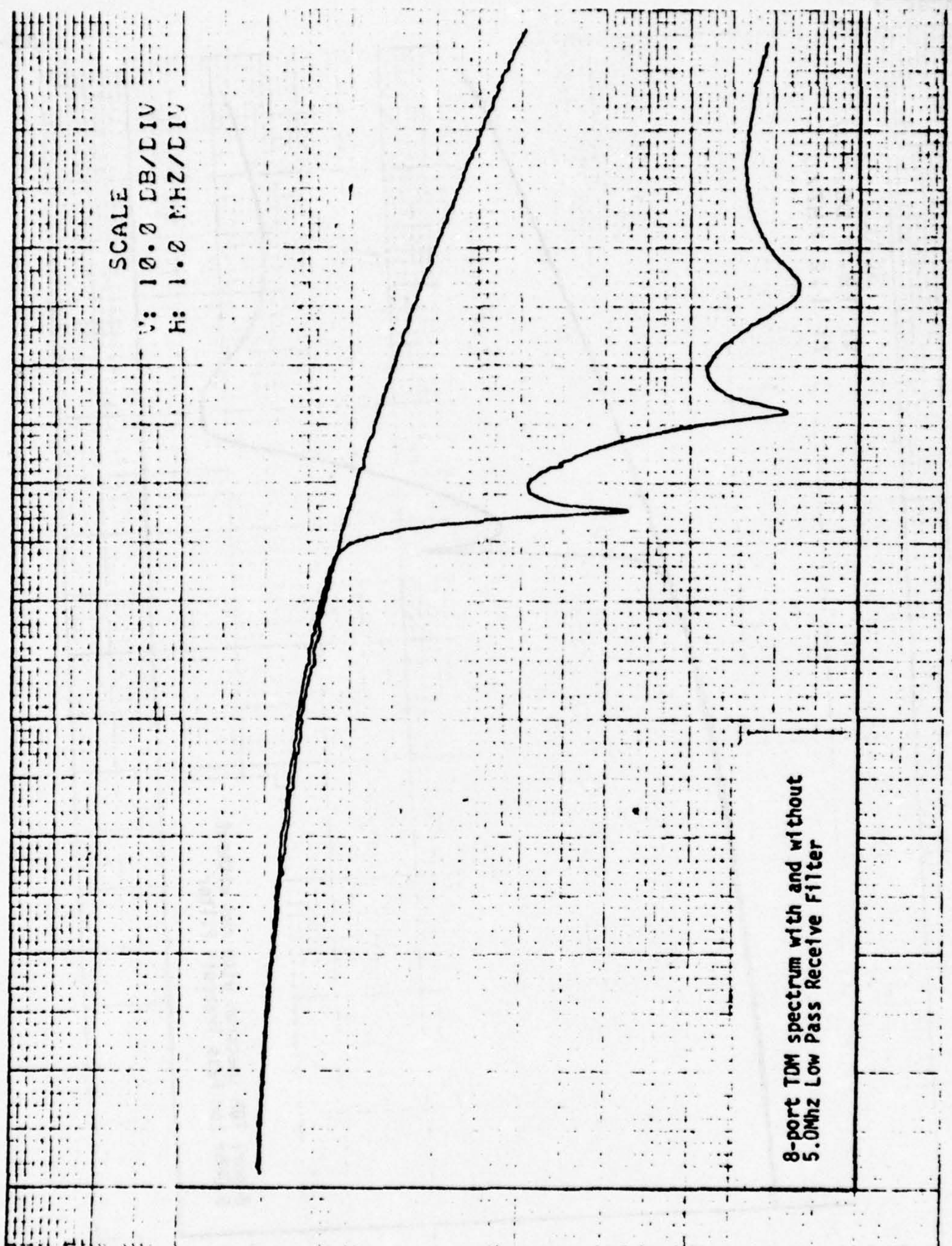
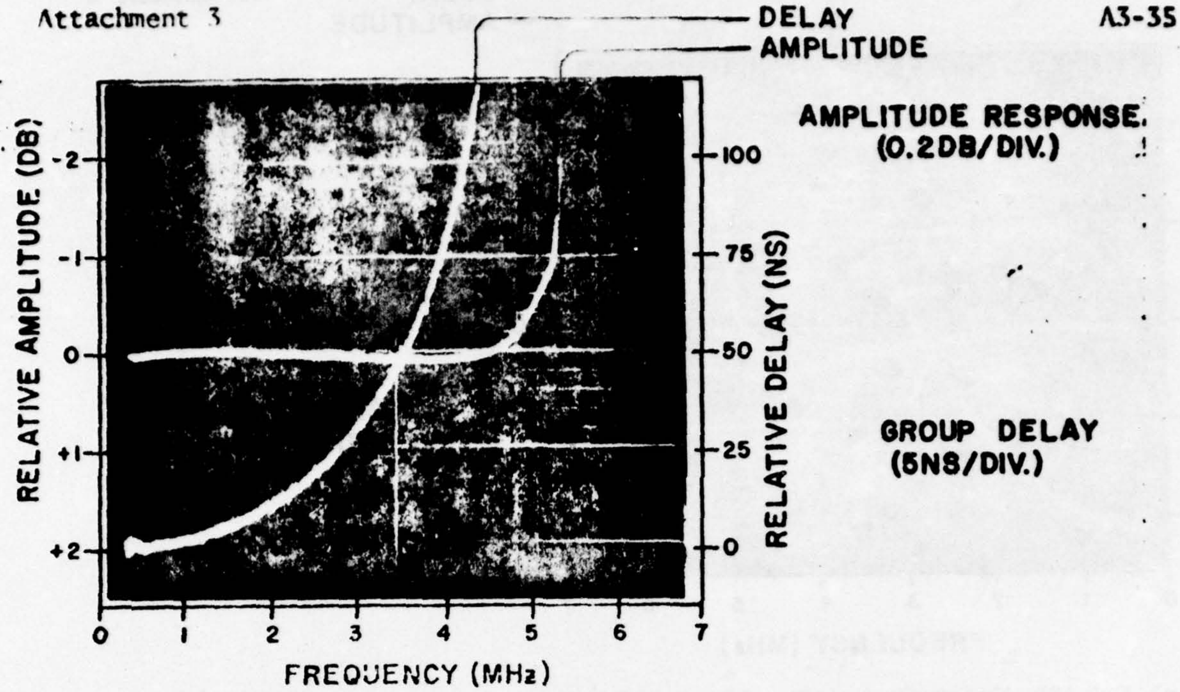
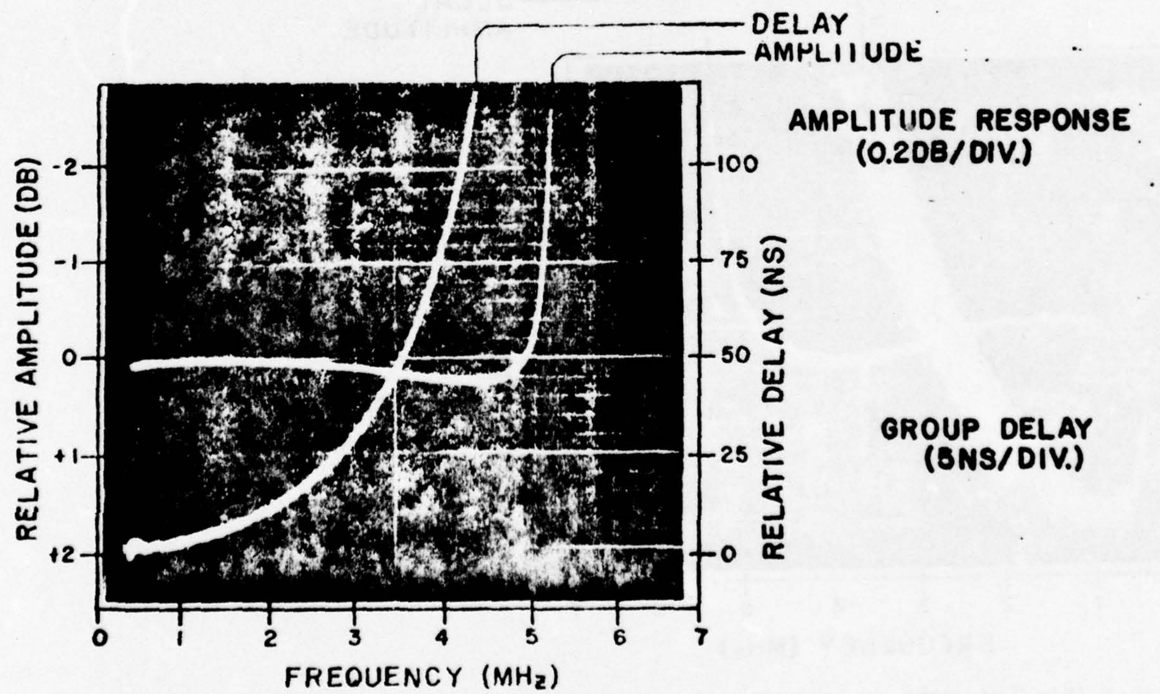

SCALE
V: 10.0 DB/DIV
H: 1.2 MHZ/DIV
8-port TDM spectrum with and without
5.0Mhz Low Pass Receive Filter

Figure A3-24

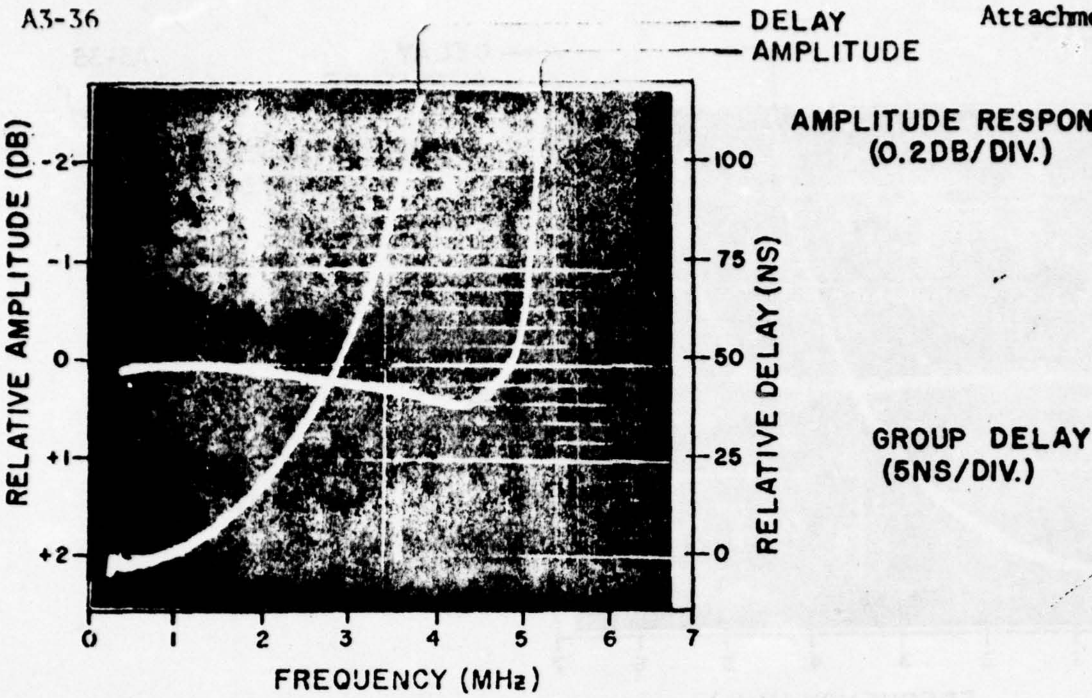


a) 5.0 MHz Transmit Low Pass Filter

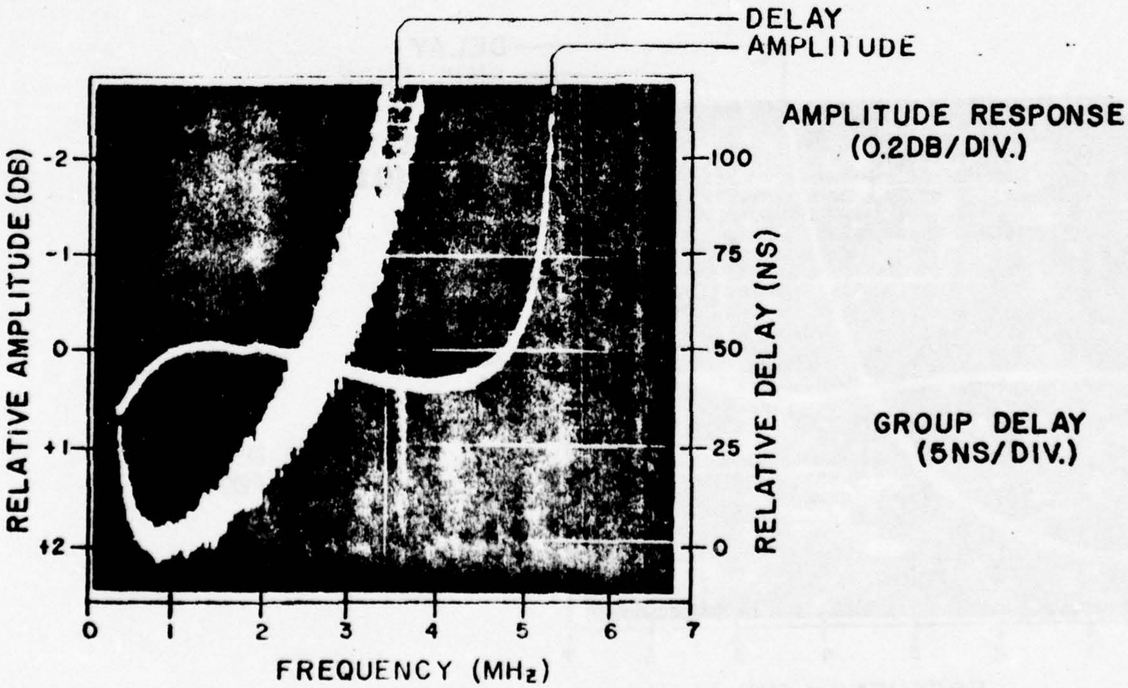


b) 5.0 MHz Receive Low Pass Filter

5.0 MHz Filter Characteristics
Figure A3-25

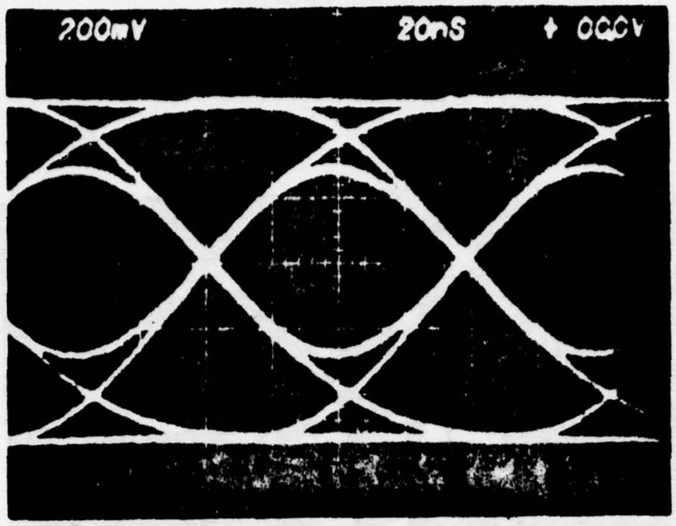


a) 5.0 MHz Transmit and Receive Low Pass Filter - back to back

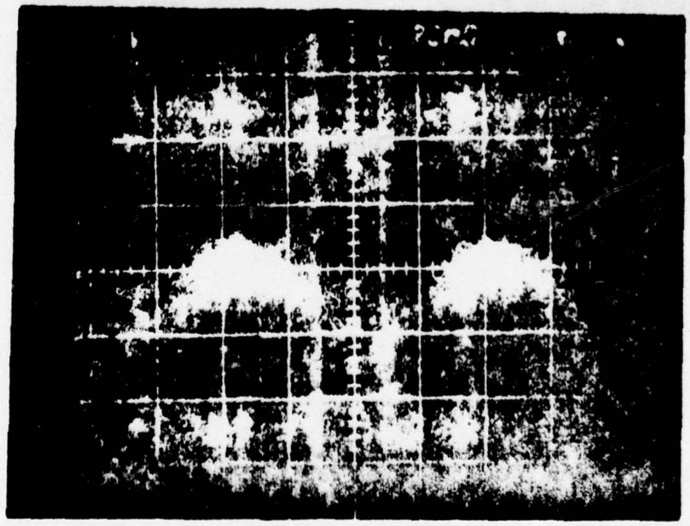


b) 5.0 MHz Transmit and Receive Low Pass Filter - over MR300 radio link

5.0 MHz Filter Characteristics
Figure A3-26

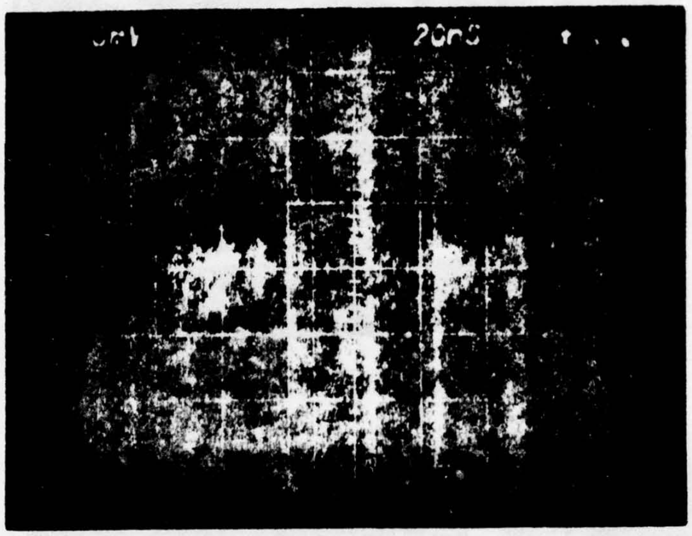


a) 8 - port TDM transmit EYE PATTERN



b) 8 - port TDM EYE PATTERN at the output of 5.0 MHz transmit LOW PASS Filter

EYE PATTERN Distortion introduced by overhead channel filters
Figure A3-27



8 - port TDM EYE PATTERN at the output of
5.0 MHz transmit and receive LOW PASS Filter
connected back to back

EYE PATTERN Distortion introduced by overhead channel filters
Figure A3-28

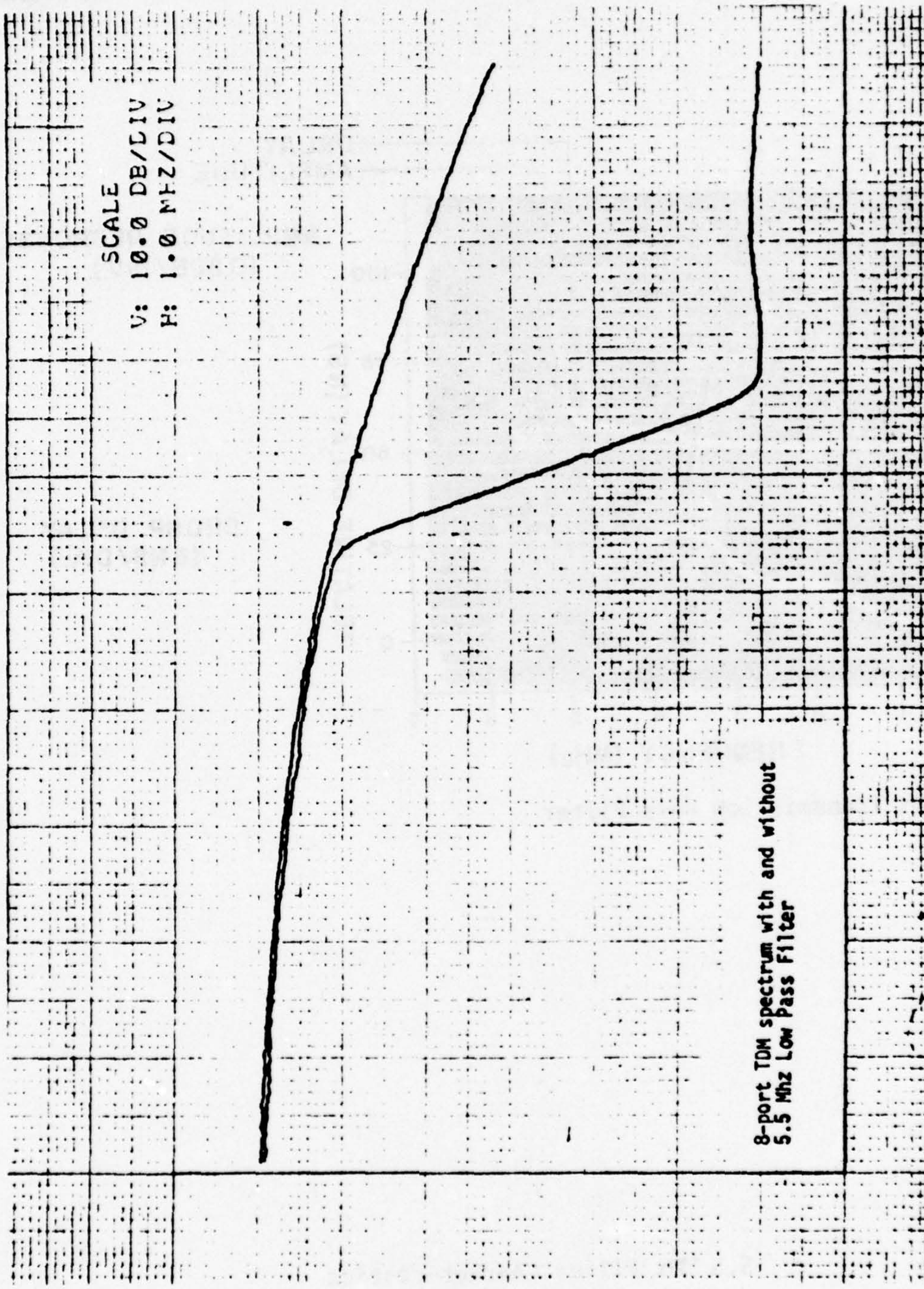
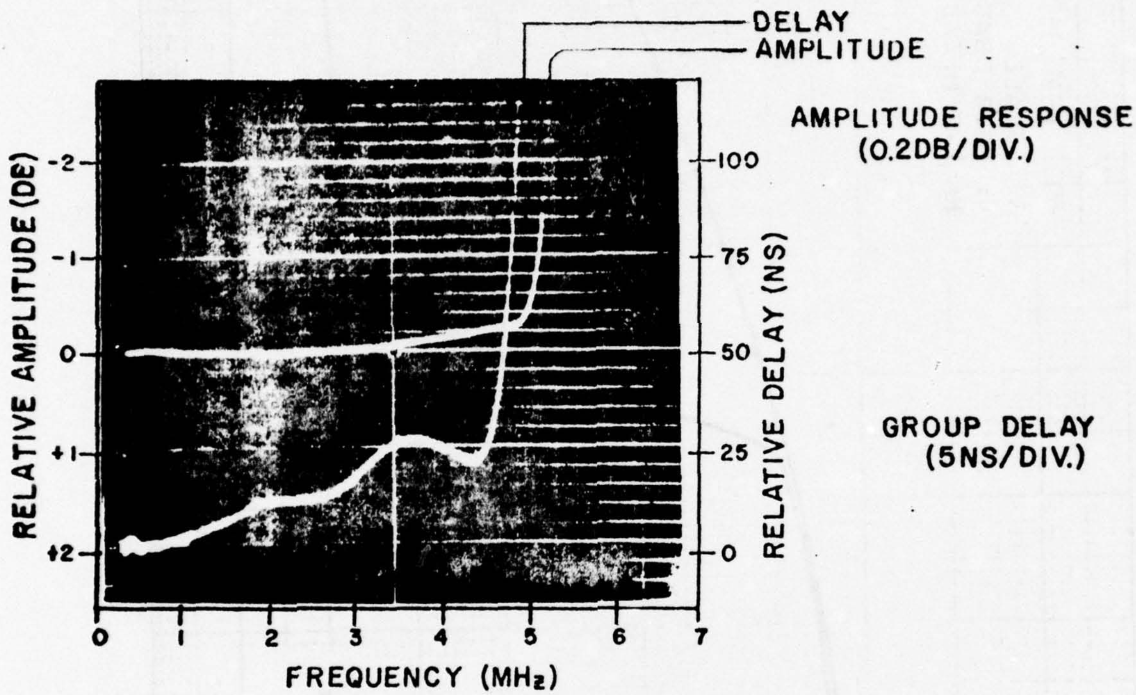
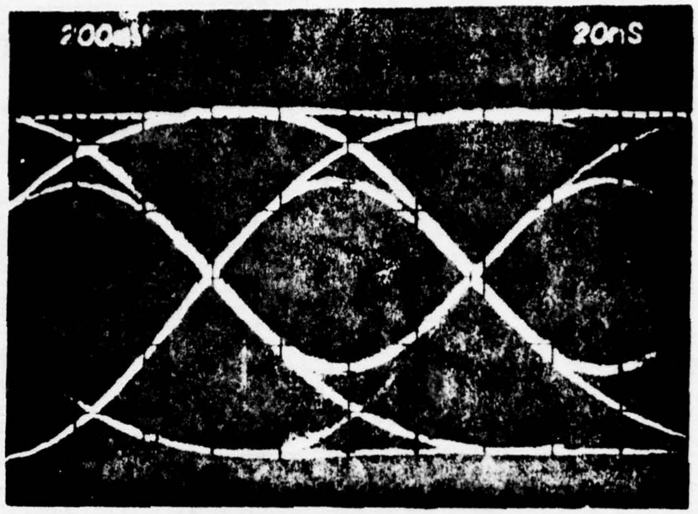

SCALE
V: 10.0 DB/DIV
H: 1.0 MHZ/DIV
8-port TDM spectrum with and without
5.5 Mhz Low Pass Filter

Figure A3-29

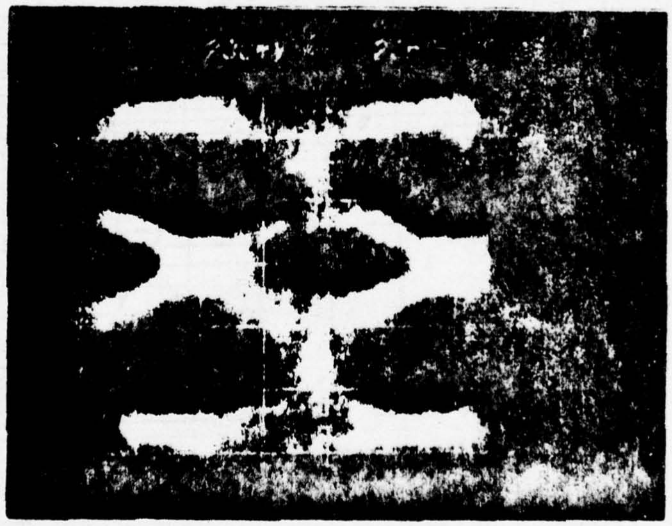


5.5 MHz Transmit Low Pass Filter

5.5 MHz Filter Characteristics
Figure A3-30



a) 8 - port TDM transmit EYE PATTERN



b) 8 - port TDM EYE PATTERN at the output of 5.5 MHz transmit LOW PASS Filter

EYE PATTERN Distortion introduced by overhead channel filters
Figure A3-31

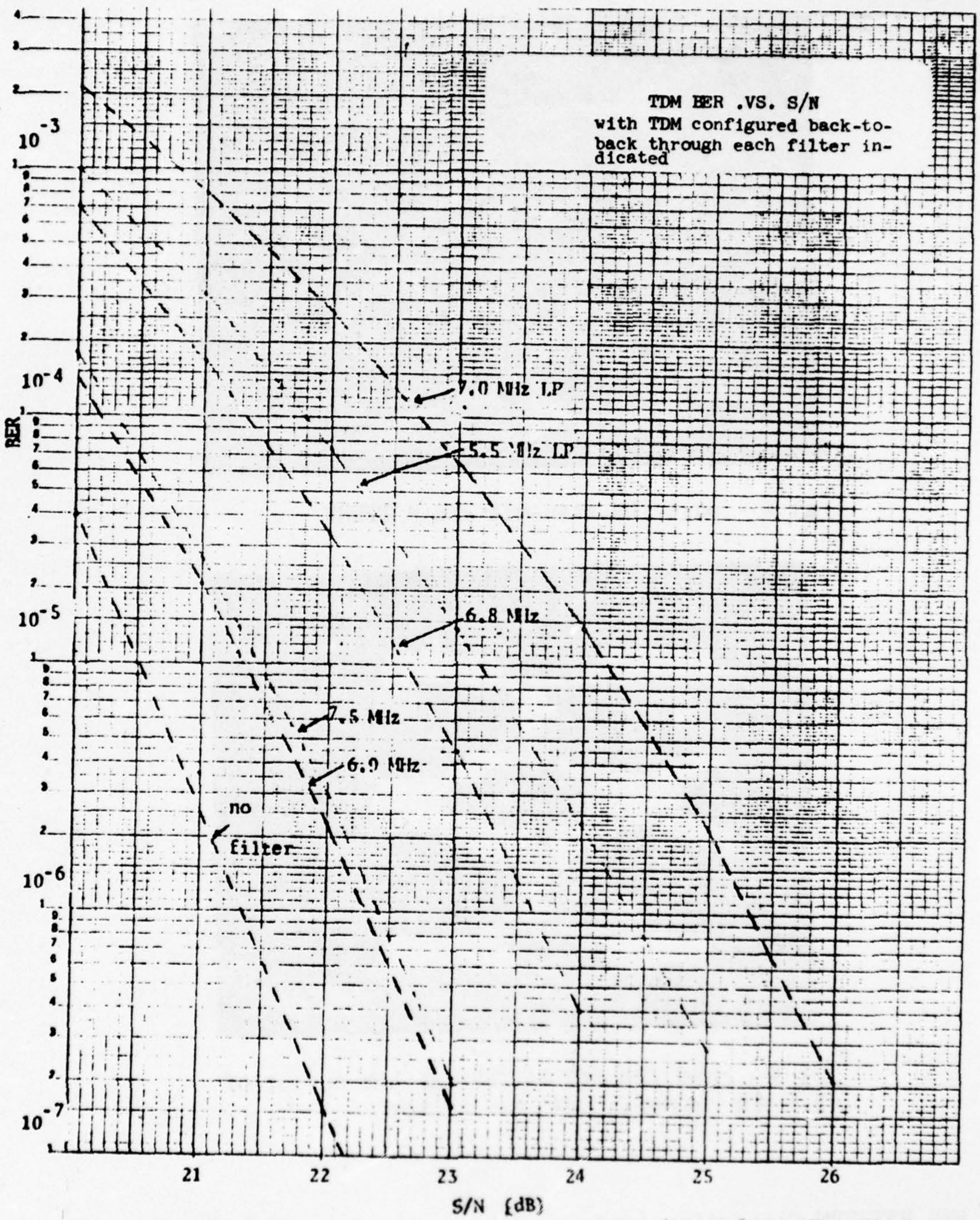

TDM BER .VS. S/N
with TDM configured back-to-back through each filter indicated
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
BER
7.0 MHz LP
5.5 MHz LP
6.8 MHz
7.5 MHz
6.9 MHz
no filter
21
22
23
24
25
26
S/N (dB)

Figure A3-32

concern; however, all the filters provided at least 30 dB of attenuation at the overhead carrier frequency.

(3) Figure A3-32 shows the results of TDM BER vs S/N for each filter under test. Note that each filter causes some increase in BER for a given S/N ratio, with the 6.9 MHz notch filter causing the least increase in BER. The 7.0 MHz low pass filter caused the most degradation with the exception of the 5.0 MHz low pass filter which would not pass the 12.6 Mbps TDM signal, and created the largest increase in BER.

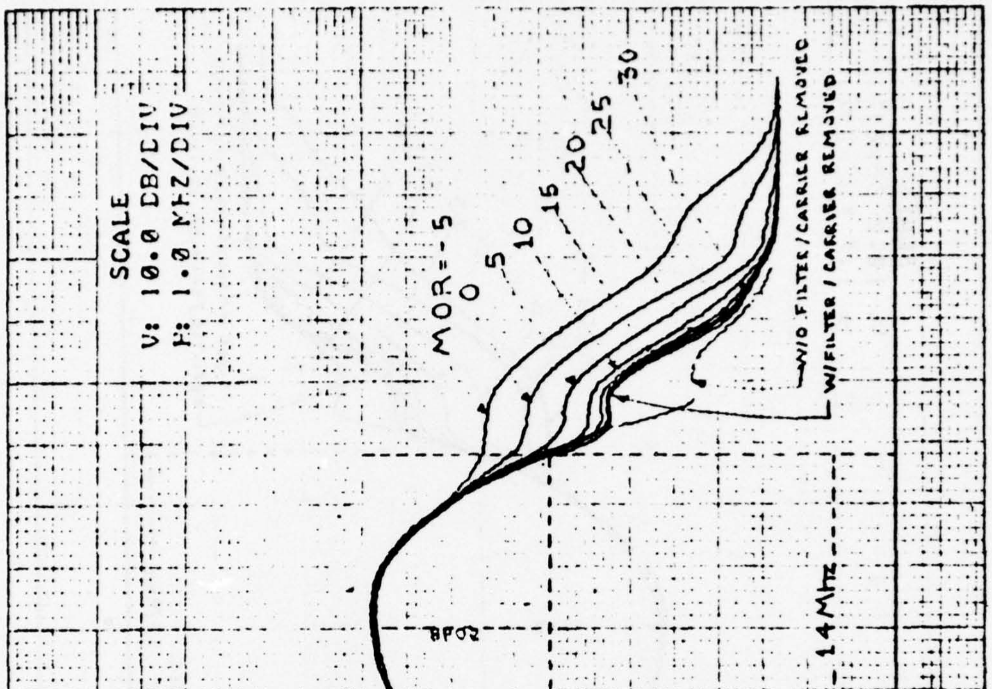
b. Transmit RF Spectrum vs MUX to Overhead Channel Ratio and Modulation Index:

(1) Figures A3-33 through A3-38 are spectrum plots, using an HP 141T spectrum analyzer, of the TDM transmitted RF spectrum for various values of multiplex to overhead channel ratio. The dotted lines on each wave form represent the 14 MHz bandwidth limits; 99% of the power is assumed to be within the 20 dB points on the wave. Note that in some of the curves f_c is offset. This is due to the difficulty in centering the RF spectrum exactly on a fixed graticule on the spectrum analyzer.

(2) From the RF frequency spectrum plots it can be seen that the 6.9 MHz notch is the only filter that limits the TDM signal to within 14 MHz although in all cases for a multiplex to overhead channel ratio of 15 the RF signal is contained within a 15 MHz bandwidth. Another method, besides filtering, to reduce RF bandwidth is to reduce the radio modulation index. Figures

A3-39 and A3-40 show the effects on the spectrum of varying the modulation index; Figures A3-41 through A3-45 show the effects with and without the 7.5 MHz notch filters. It can be seen that reducing the modulation index does reduce the RF bandwidth, but at the expense of signal degradation. Figures A3-46 and A3-47 show the response of the degradation monitor for changes in the receive signal level. Incremental changes in modulation index are also super-superimposed on these plots.

c. TDM Baseband Frequency Spectrum and Overhead Channel C/N Measurements. Baseband frequency spectrum plots were made for both the transmit and receive TDM signal over a MR-300 radio link (see Figures A3-48 through A3-57). Quantitative power measurements were also made using a HP 312 selective volt-meter to determine the overhead channel carrier level with respect to the noise levels at the 20 KHz increments on either side of the overhead channel carrier. See Figure A3-58 for a graph of the test results that show the effects of the multiplex to overhead channel ratio on overhead channel C/N ratio for each filter tested. Figure A3-58 verifies an obvious assumption that the overhead channel C/N decreases with increasing multiplex to overhead channel ratio. The largest values from overhead channel C/N resulted with using the overhead channel low pass filter, which effectively reduced the transmitted TDM baseband cut-off frequency and significantly reduced the out of band TDM signal which could be a major contributor to intermodulation noise produced in the ratio. This increase in C/N ratio, which is a desired condition,



Transmit R-F spectrum for varying MOR using 6.9 MHz notch filter and 6.9 MHz carrier

Figure A3-33

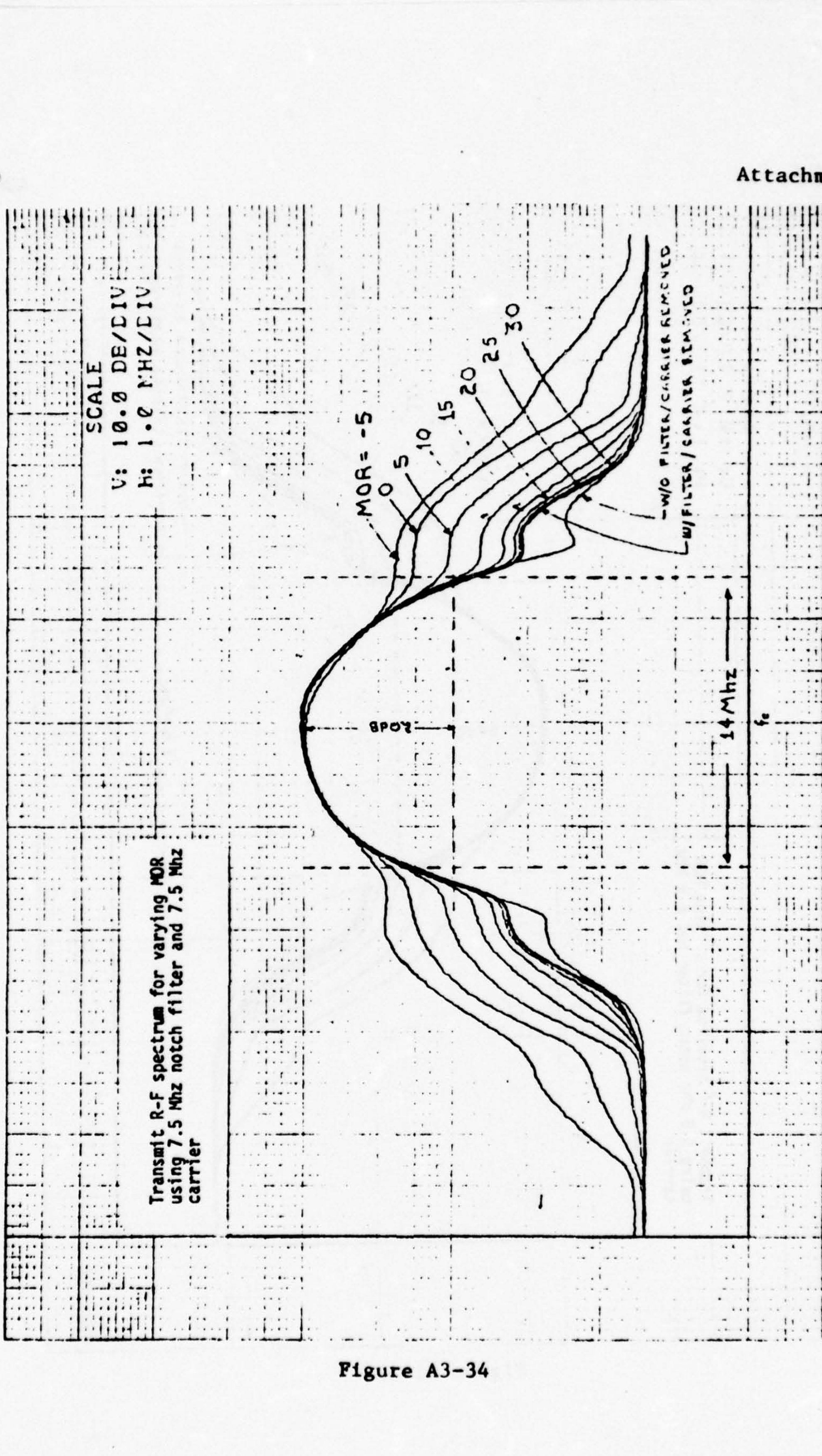

SCALE
V: 10.0 DB/DIV
H: 1.0 MHZ/DIV
Transmit R-F spectrum for varying MDR using 7.5 Mhz notch filter and 7.5 Mhz carrier
MOR= -5
0
5
10
15
20
25
30
W/O FILTER/CARRIER REMOVED
W/FILTER/CARRIER REMOVED
14 Mhz

Figure A3-34

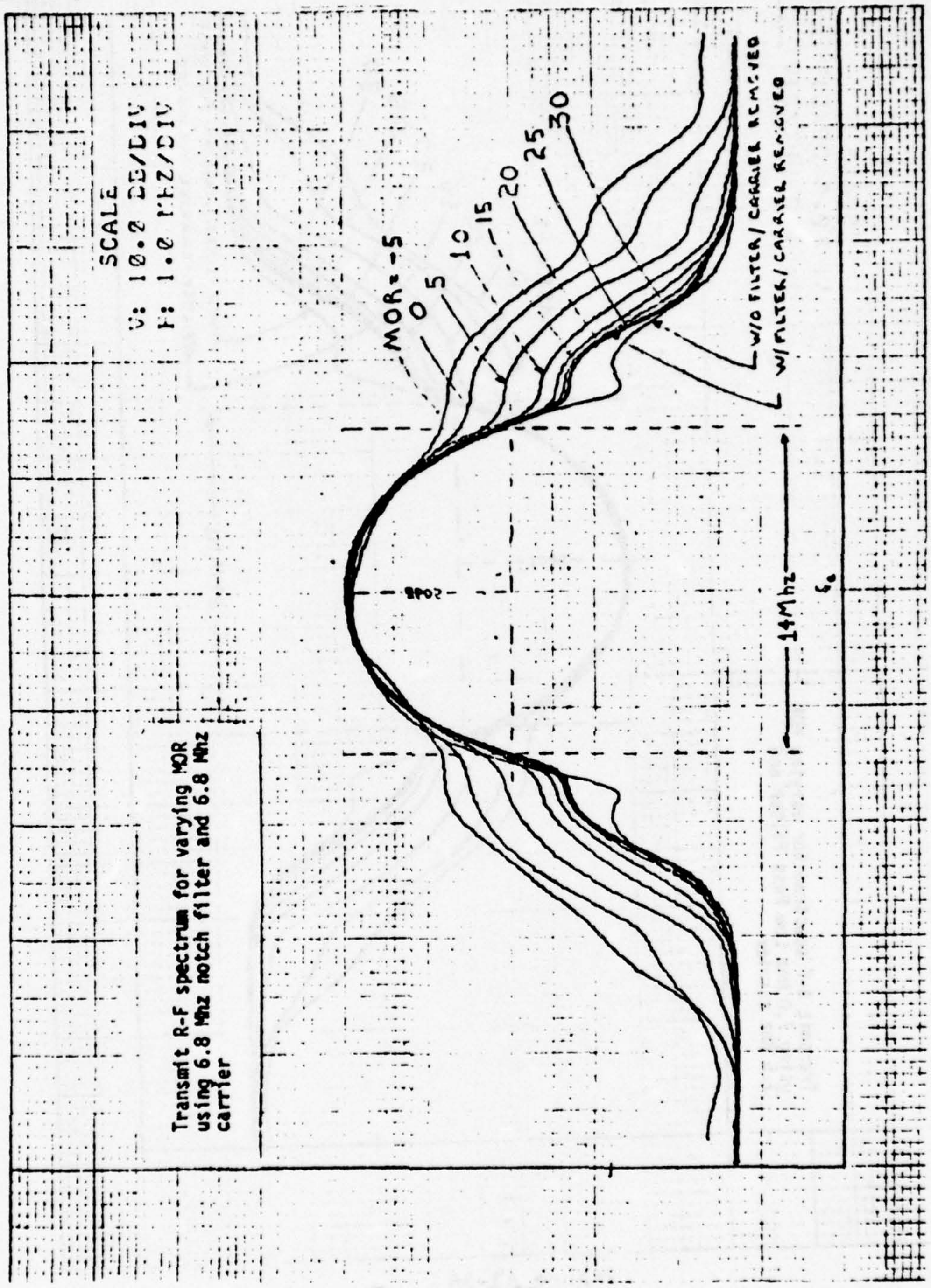

SCALE
V: 10.0 DB/DIV
H: 1.0 MHZ/DIV
Transmit R-F spectrum for varying MOR using 6.8 Mhz notch filter and 6.8 Mhz carrier
MOR= -5
0
5
10
15
20
25
30
W/O FILTER/CARRIER REMOVED
W/FILTER/CARRIER REMOVED
14Mhz

Figure A3-35

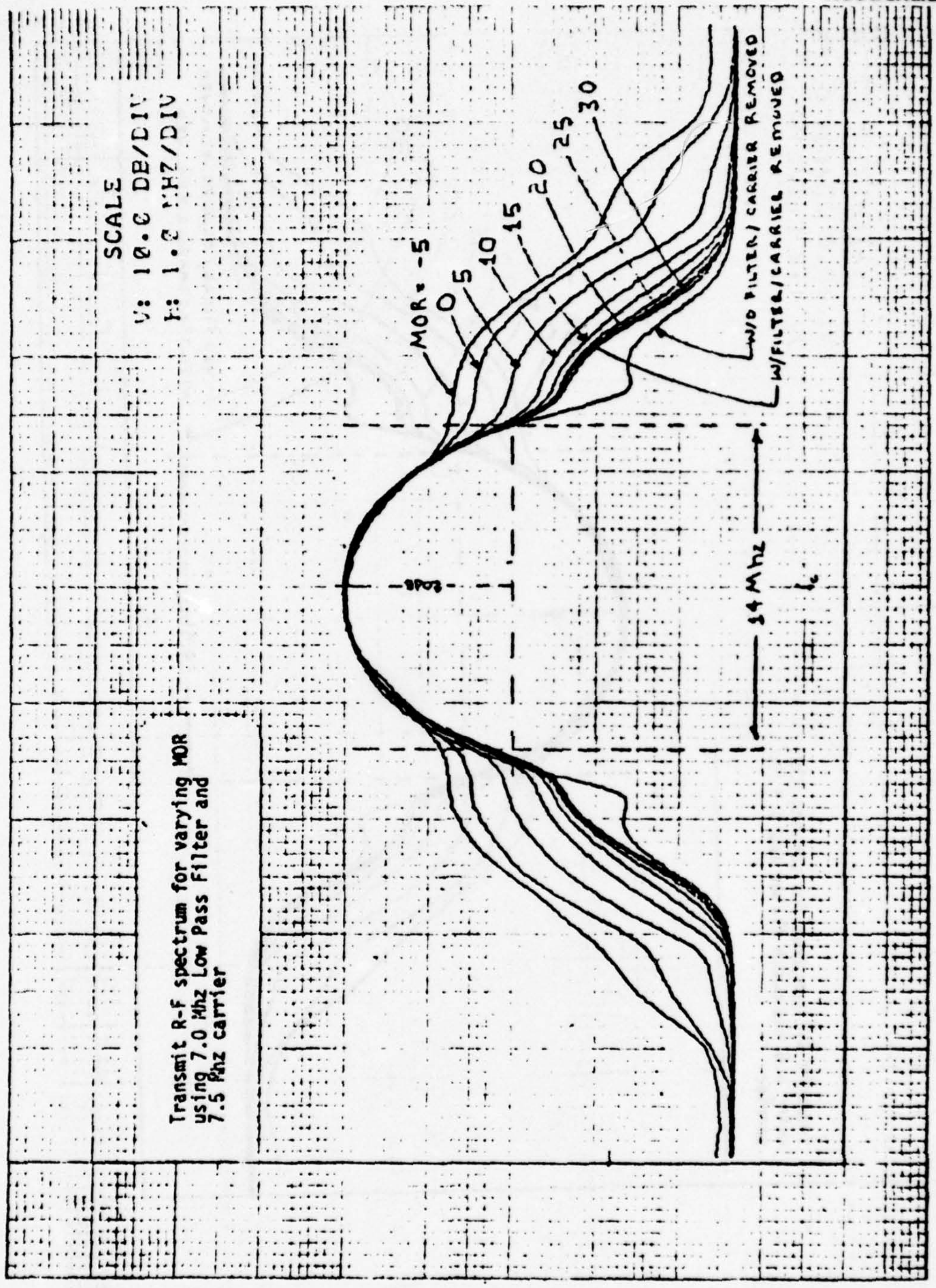

SCALE
V: 10.0 DB/DIV
H: 1.2 MHZ/DIV
Transmit R-F spectrum for varying MOR using 7.0 Mhz Low Pass Filter and 7.5 Mhz carrier
MOR= -5
0
5
10
15
20
25
30
W/O FILTER/CARRIER REMOVED
W/FILTER/CARRIER REMOVED
14 Mhz

Figure A3-36

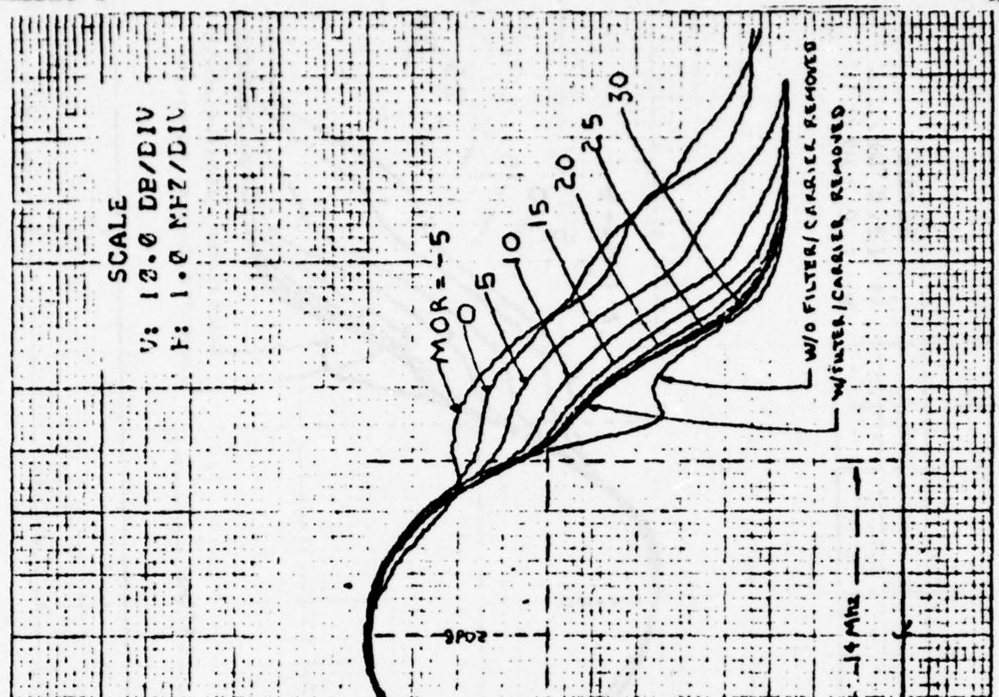

SCALE
V: 10.0 DB/DIV
H: 1.0 MHZ/DIV
MOR = -5
0
5
10
15
20
25
30
W/O FILTER/CARRIER REMOVED
W/FILTER/CARRIER REMOVED
20dB
14 Mhz
Transmit R-F spectrum for varying Mor using 5.0 Mhz Low Pass Filter and 6.8 Mhz carrier

Figure A3-37

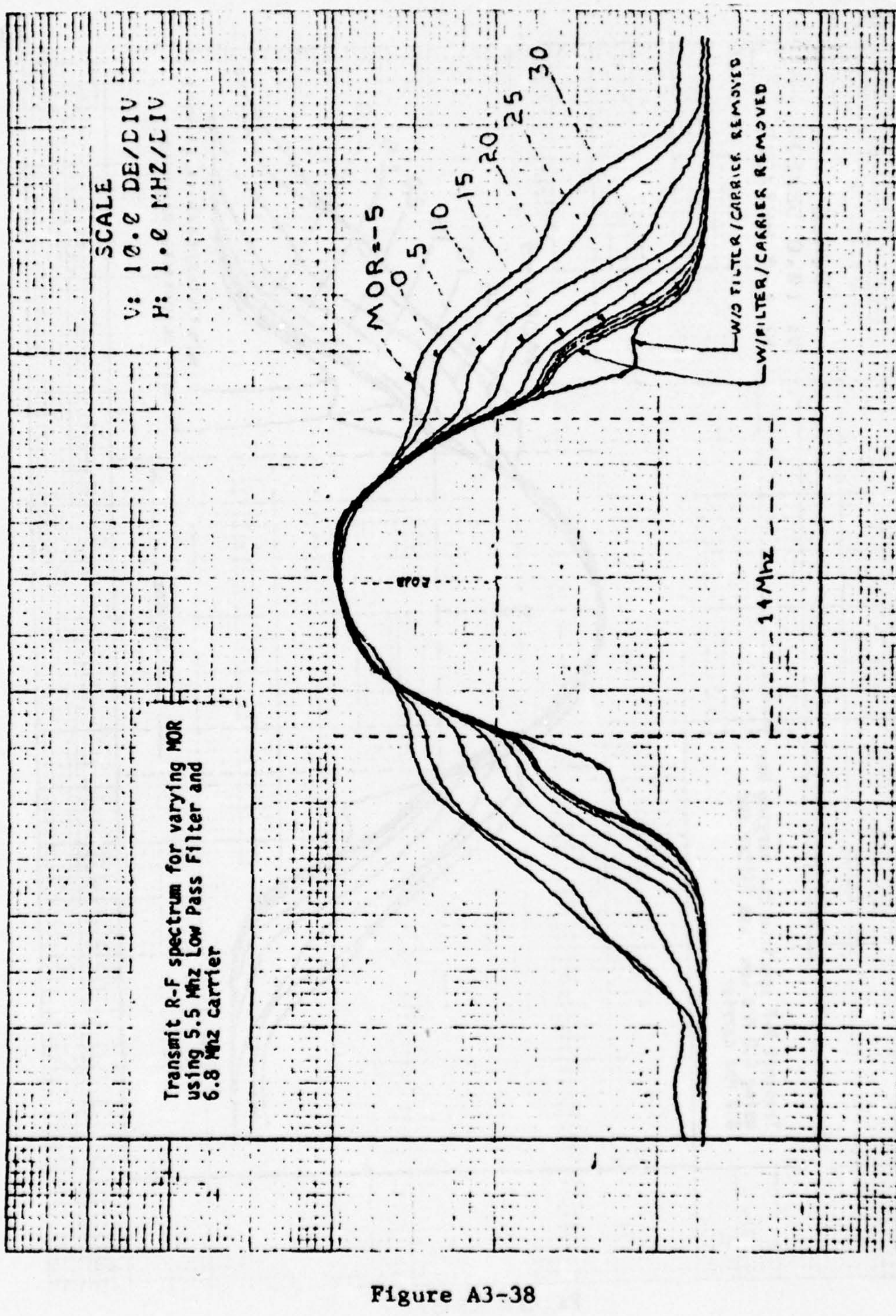

SCALE
V: 10.0 DB/DIV
H: 1.0 MHZ/DIV
MOR=-5
0
5
10
15
20
25
30
W/O FILTER/CARRIER REMOVED
W/FILTER/CARRIER REMOVED
14 Mhz
Transmit R-F spectrum for varying MOR using 5.5 Mhz Low Pass Filter and 6.8 Mhz carrier

Figure A3-38

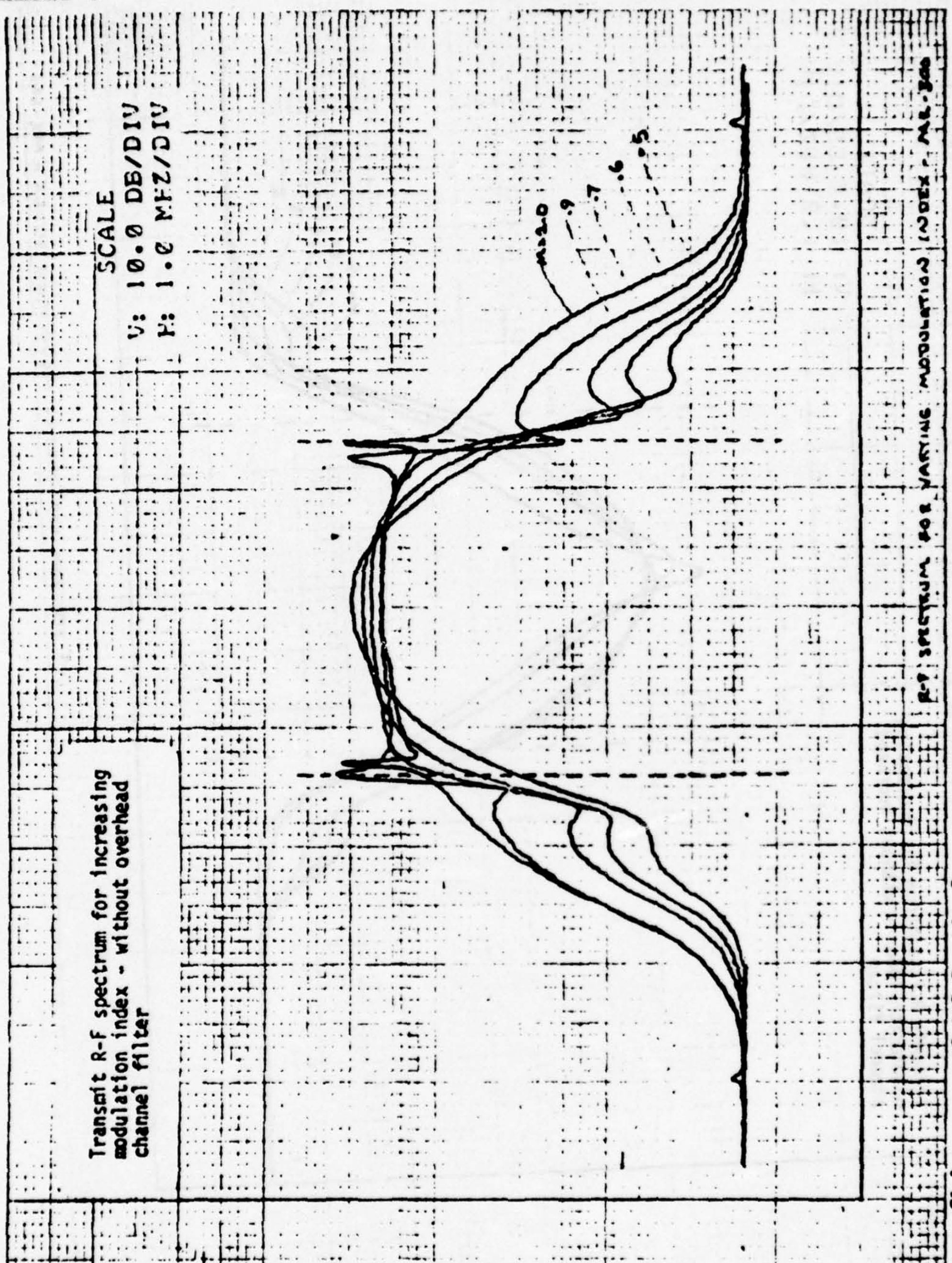

SCALE
V: 10.0 DB/DIV
H: 1.0 MHZ/DIV
Transmit R-F spectrum for increasing modulation index - without overhead channel filter
.9
.7
.6
.5
R-F SPECTRUM FOR VARYING MODULATION INDEX

Figure A3-39

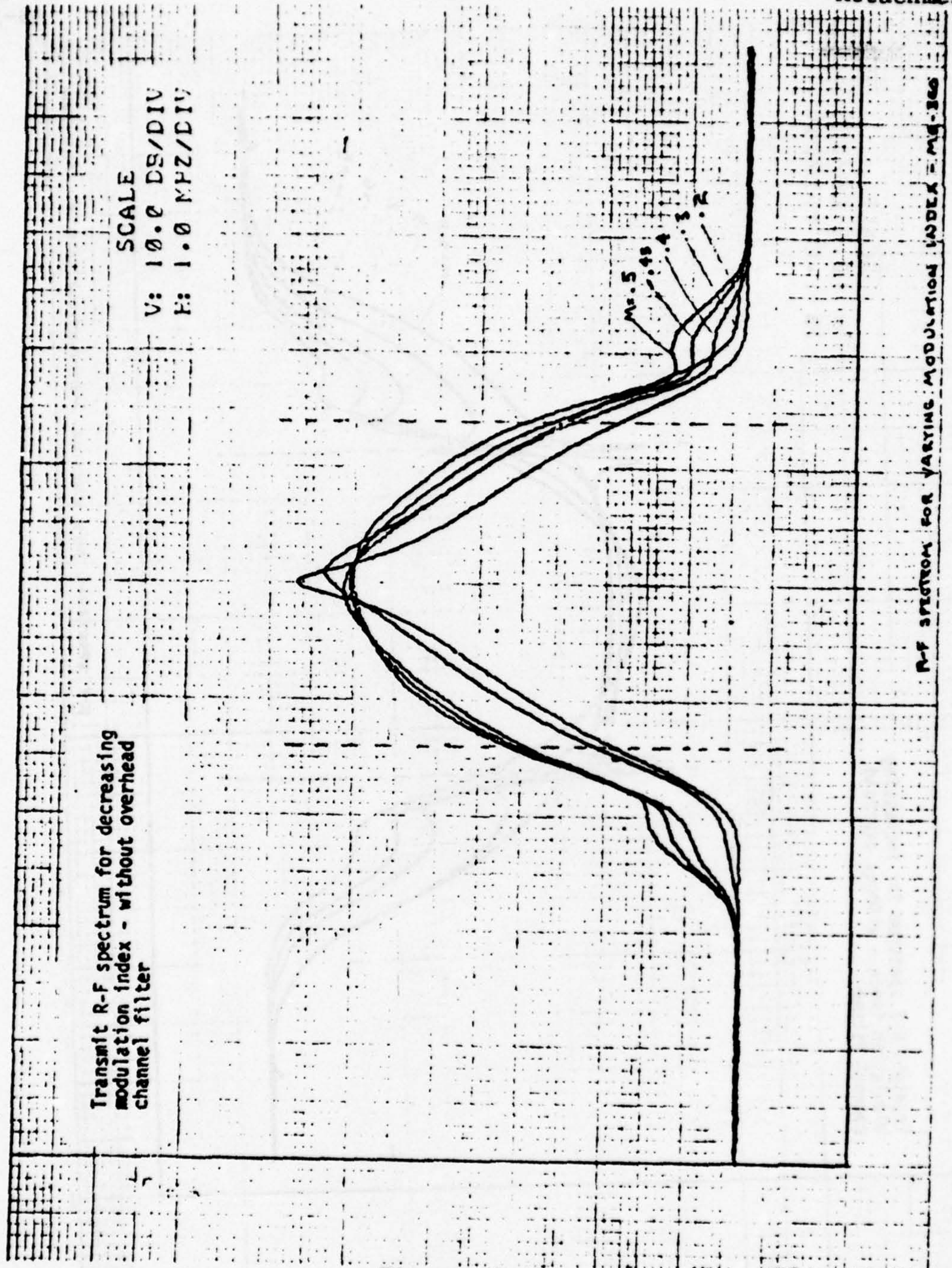

SCALE
V: 10.0 DB/DIV
H: 1.0 MHZ/DIV
Transmit R-F spectrum for decreasing modulation index - without overhead channel filter
M=.5
.45
.4
.3
.2

Figure A3-40

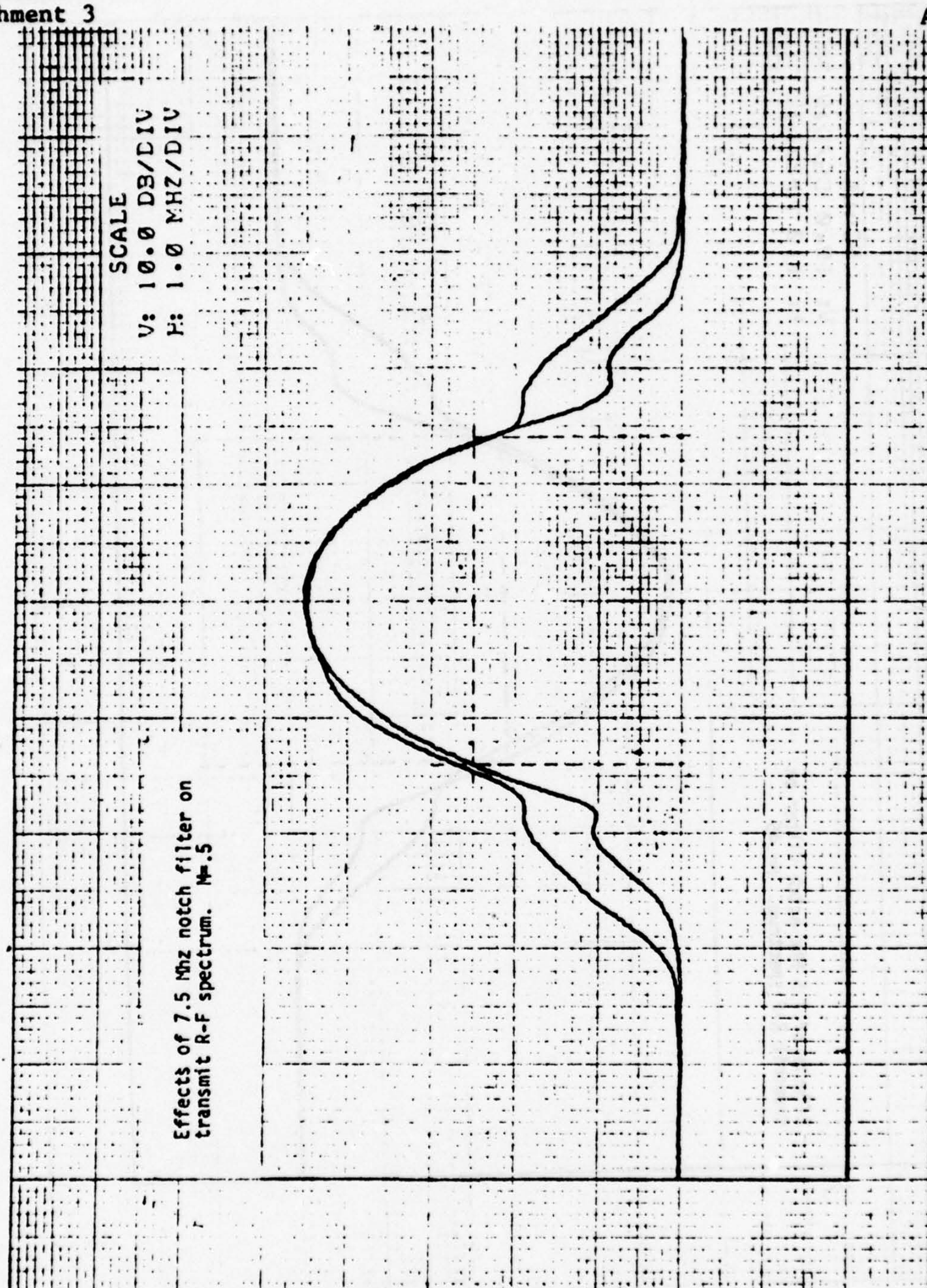

SCALE
V: 10.0 DB/DIV
H: 1.0 MHZ/DIV
Effects of 7.5 Mhz notch filter on transmit R-F spectrum. M=.5

Figure A3-41

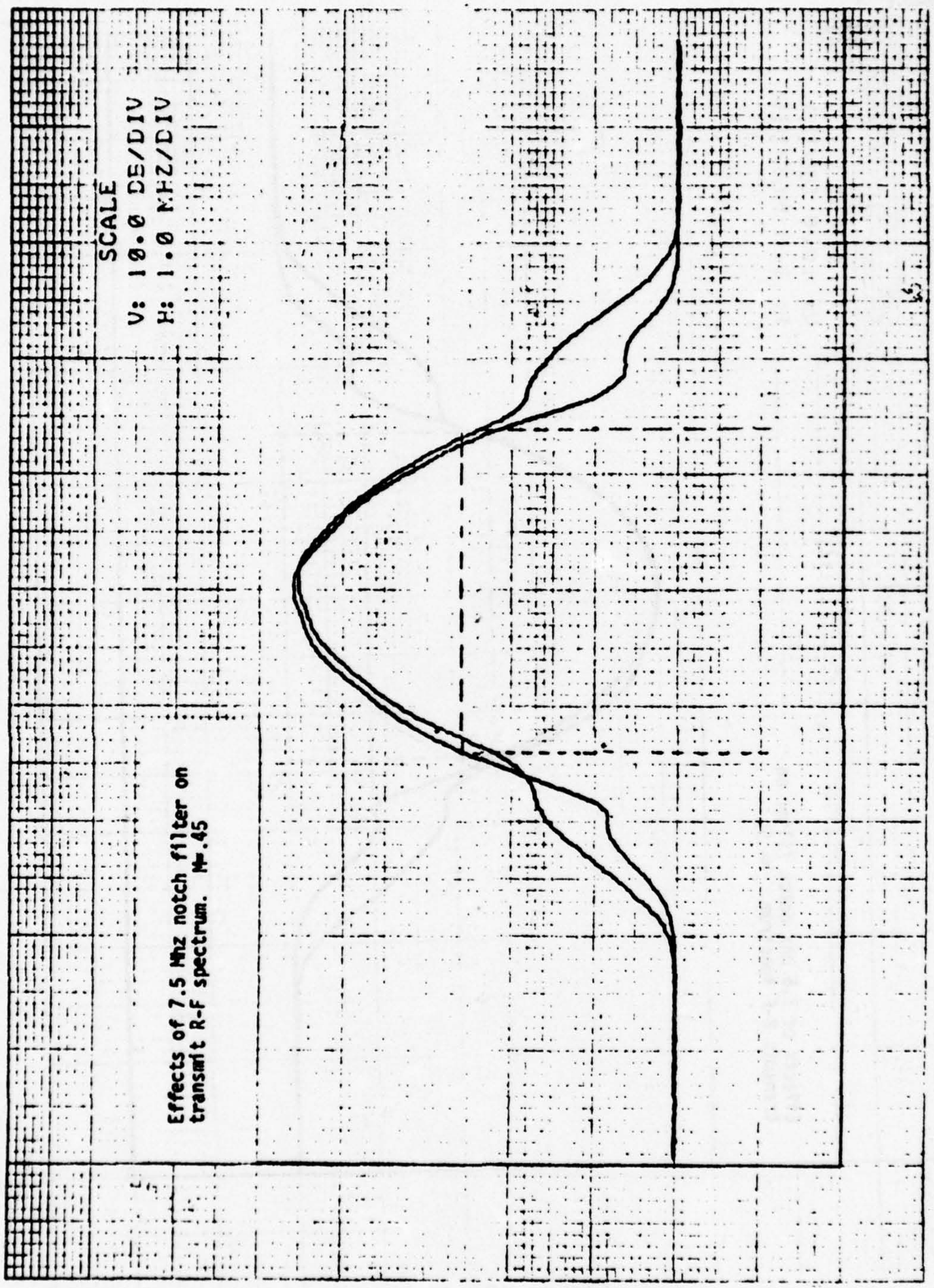
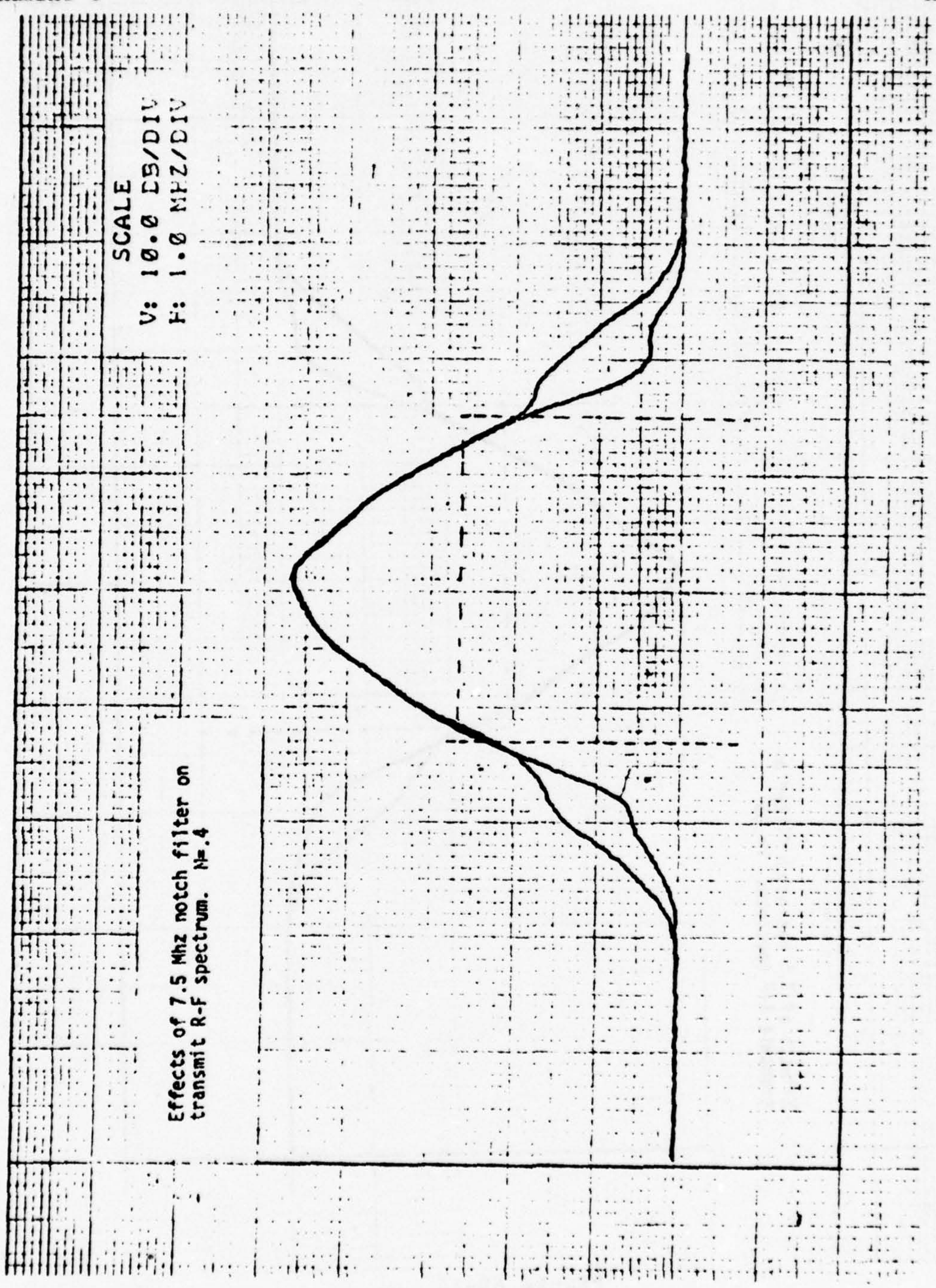
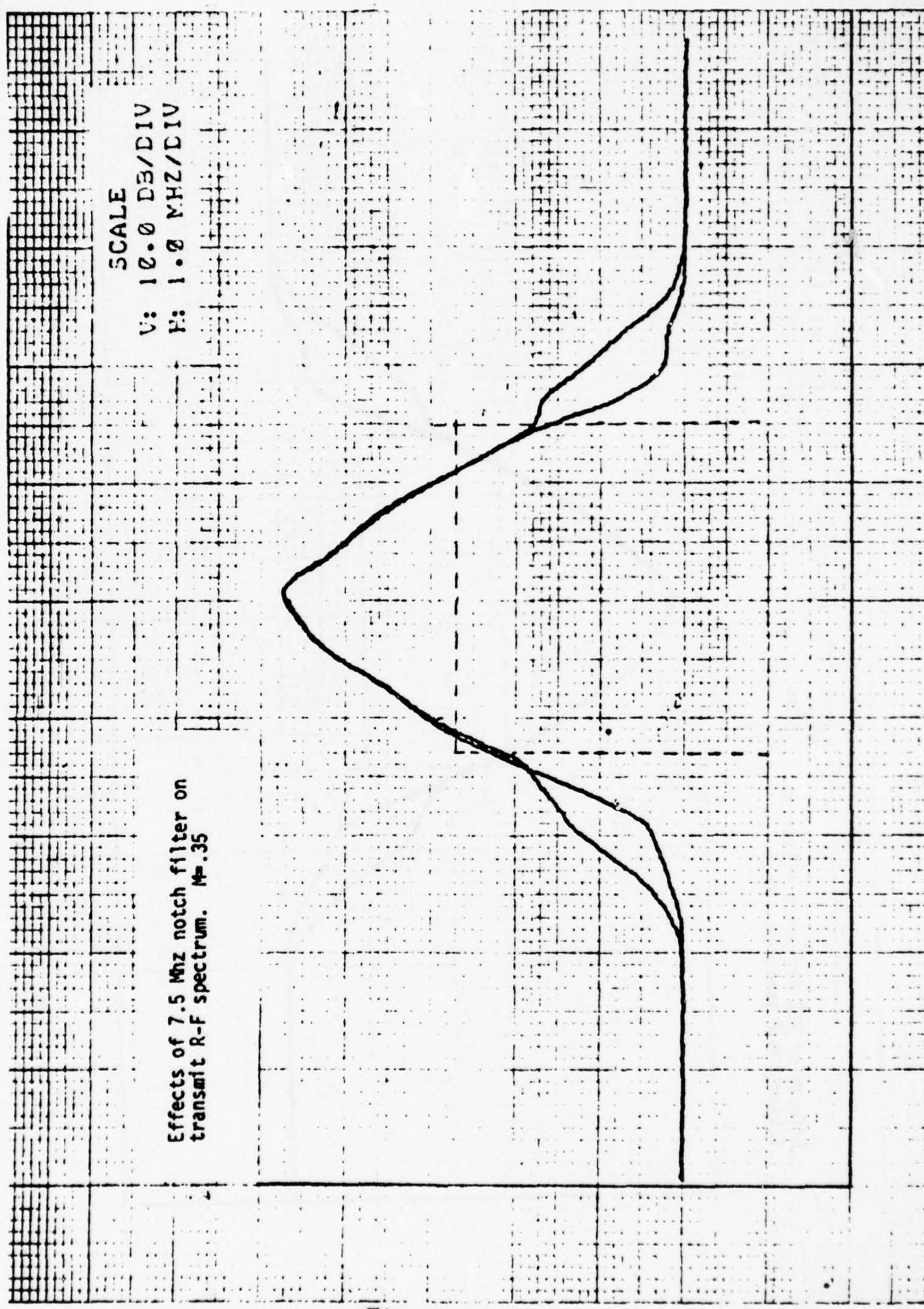

SCALE
V: 10.0 DB/DIV
H: 1.0 MHZ/DIV
Effects of 7.5 Mhz notch filter on transmit R-F spectrum. N=.45

Figure A3-42



Effects of 7.5 Mhz notch filter on transmit R-F spectrum. N=.4

Figure A3-43



Effects of 7.5 Mhz notch filter on transmit R-F spectrum. M=.35

Figure A3-44

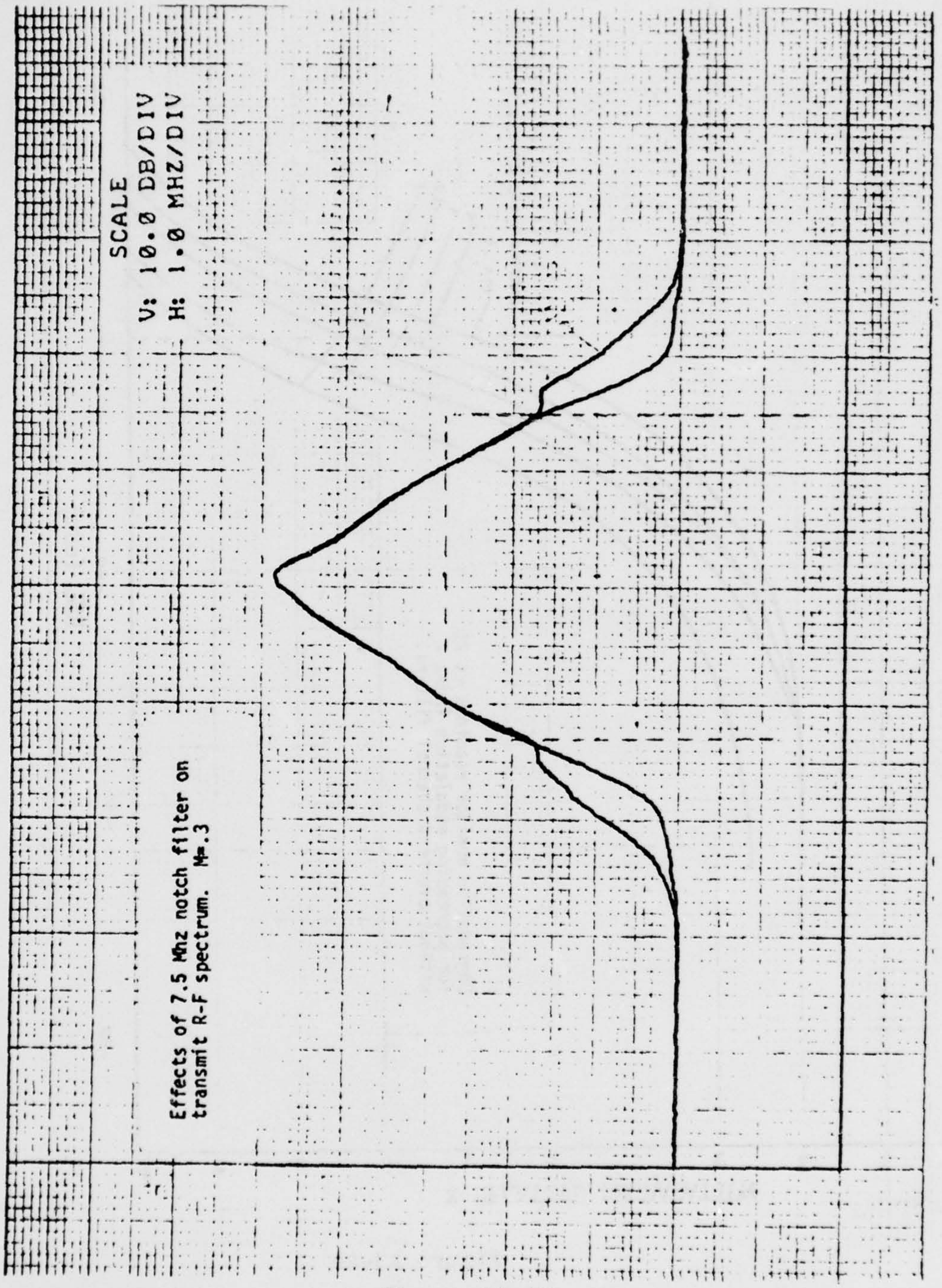

SCALE
V: 10.0 DB/DIV
H: 1.0 MHZ/DIV
Effects of 7.5 Mhz notch filter on transmit R-F spectrum. M=.3

Figure A3-45

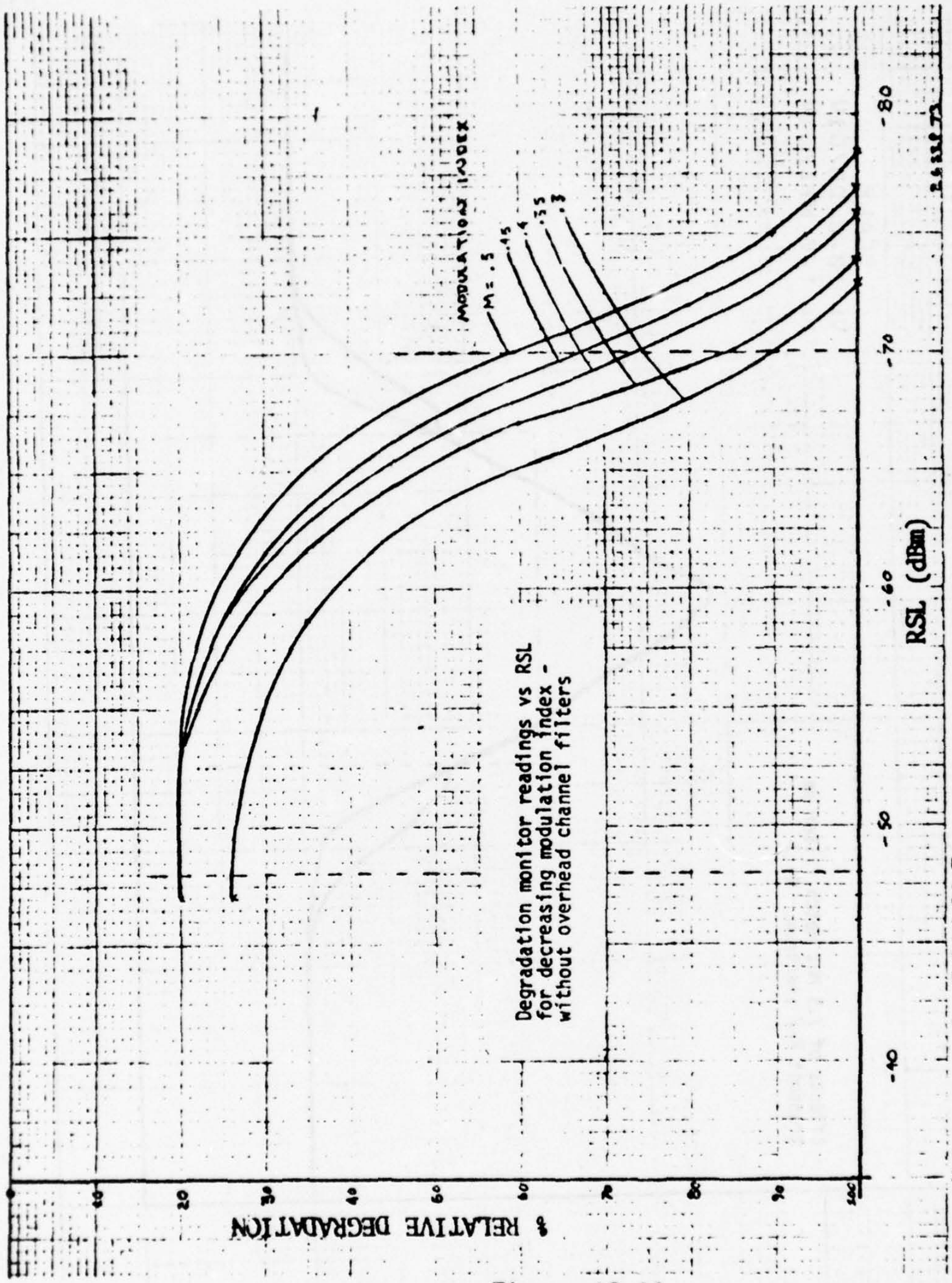

Degradation monitor readings vs RSL
for decreasing modulation index -
without overhead channel filters
MODULATION INDEX
M = .5
.45
.4
.35
.3
% RELATIVE DEGRADATION
RSL (dBm)
-40
-50
-60
-70
-80

Figure A3-46

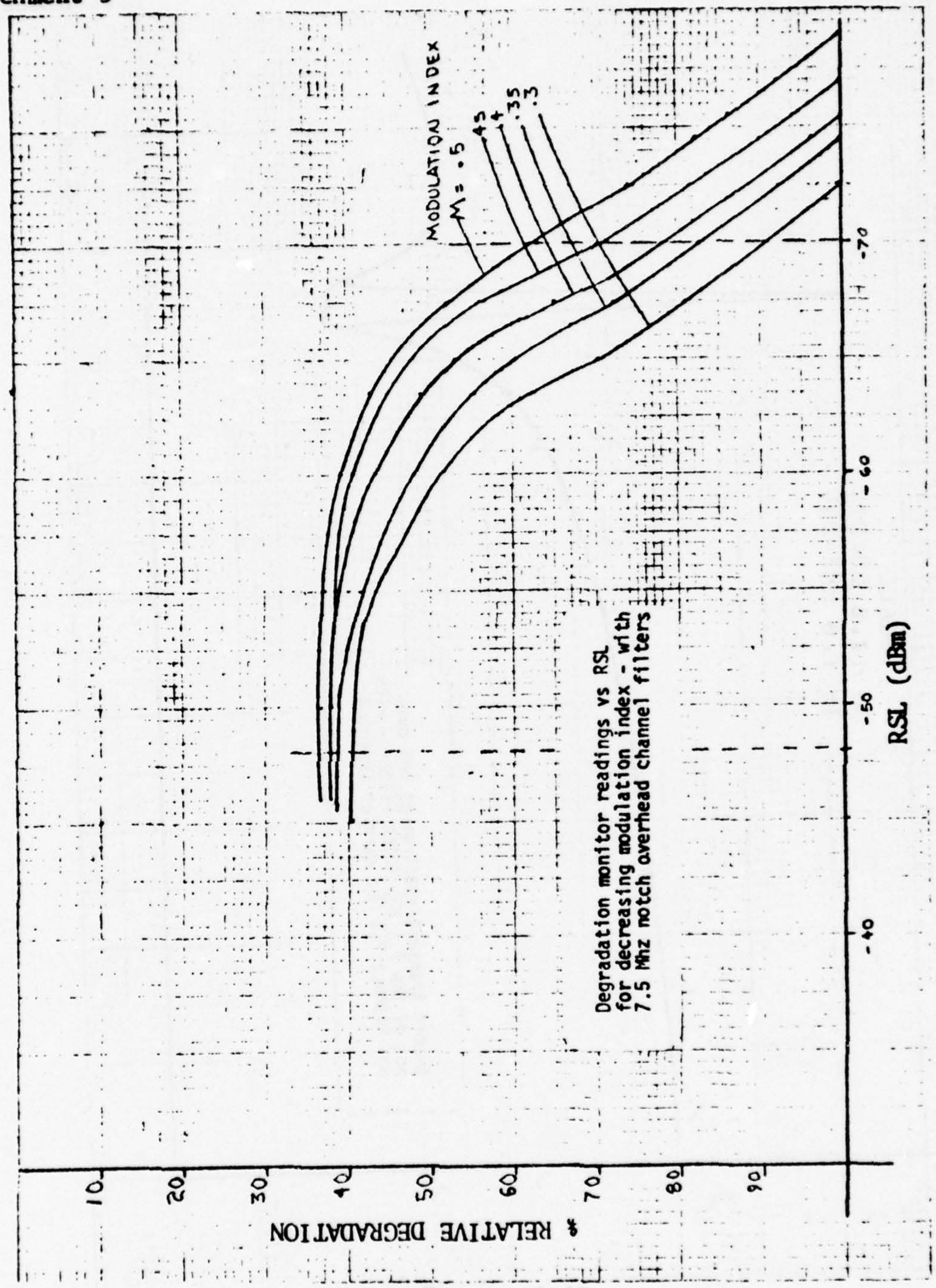

Degradation monitor readings vs RSL
for decreasing modulation index - with
7.5 Mhz notch overhead channel filters
MODULATION INDEX
M= .5
.45
.4
.35
.3
-40
-50
-60
-70
RSL (dBm)
10
20
30
40
50
60
70
80
90
% RELATIVE DEGRADATION

Figure A3-47

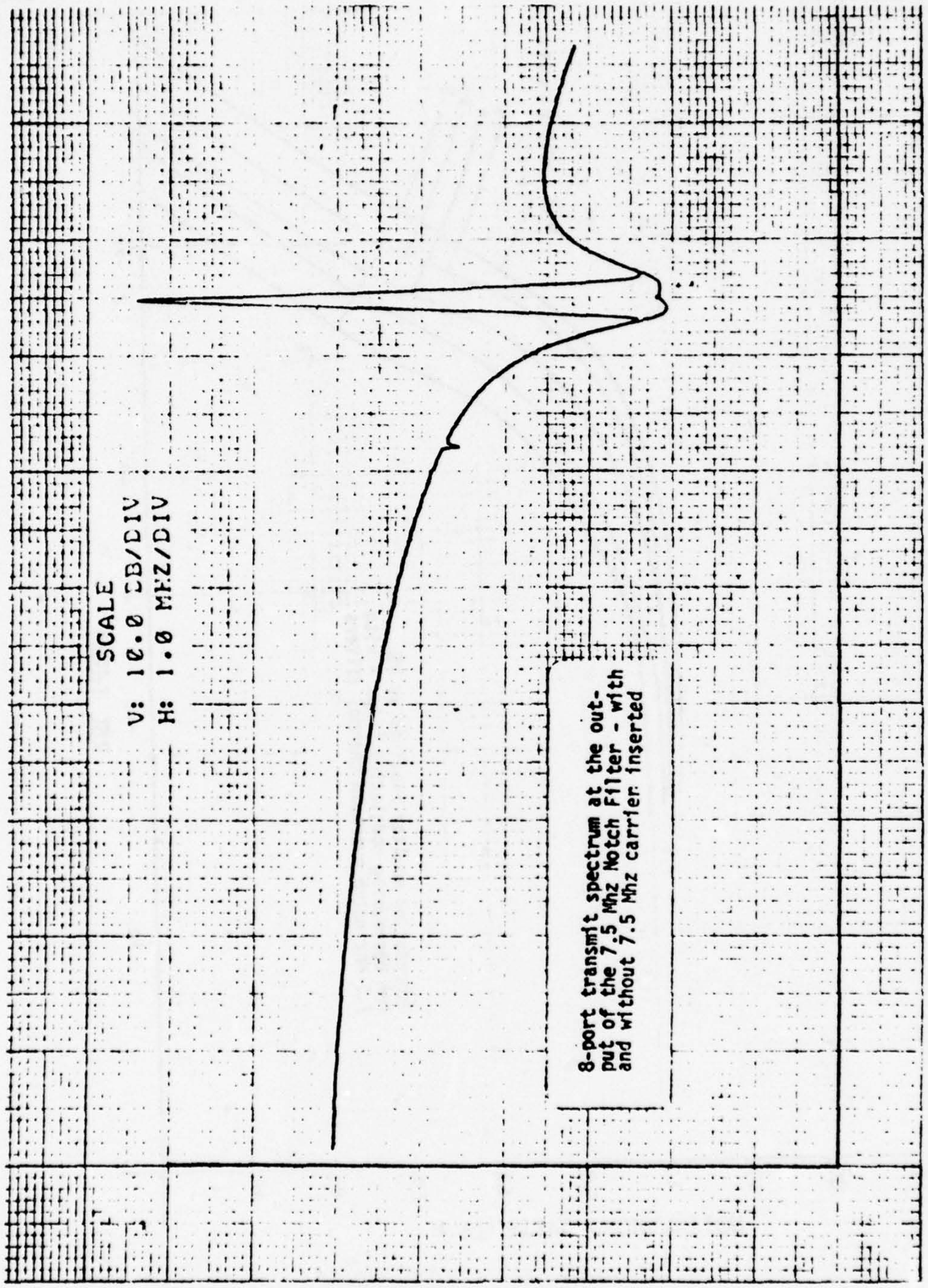

SCALE
V: 10.0 DB/DIV
H: 1.0 MHZ/DIV
8-port transmit spectrum at the output of the 7.5 Mhz Notch Filter - with and without 7.5 Mhz carrier inserted

Figure A3-48

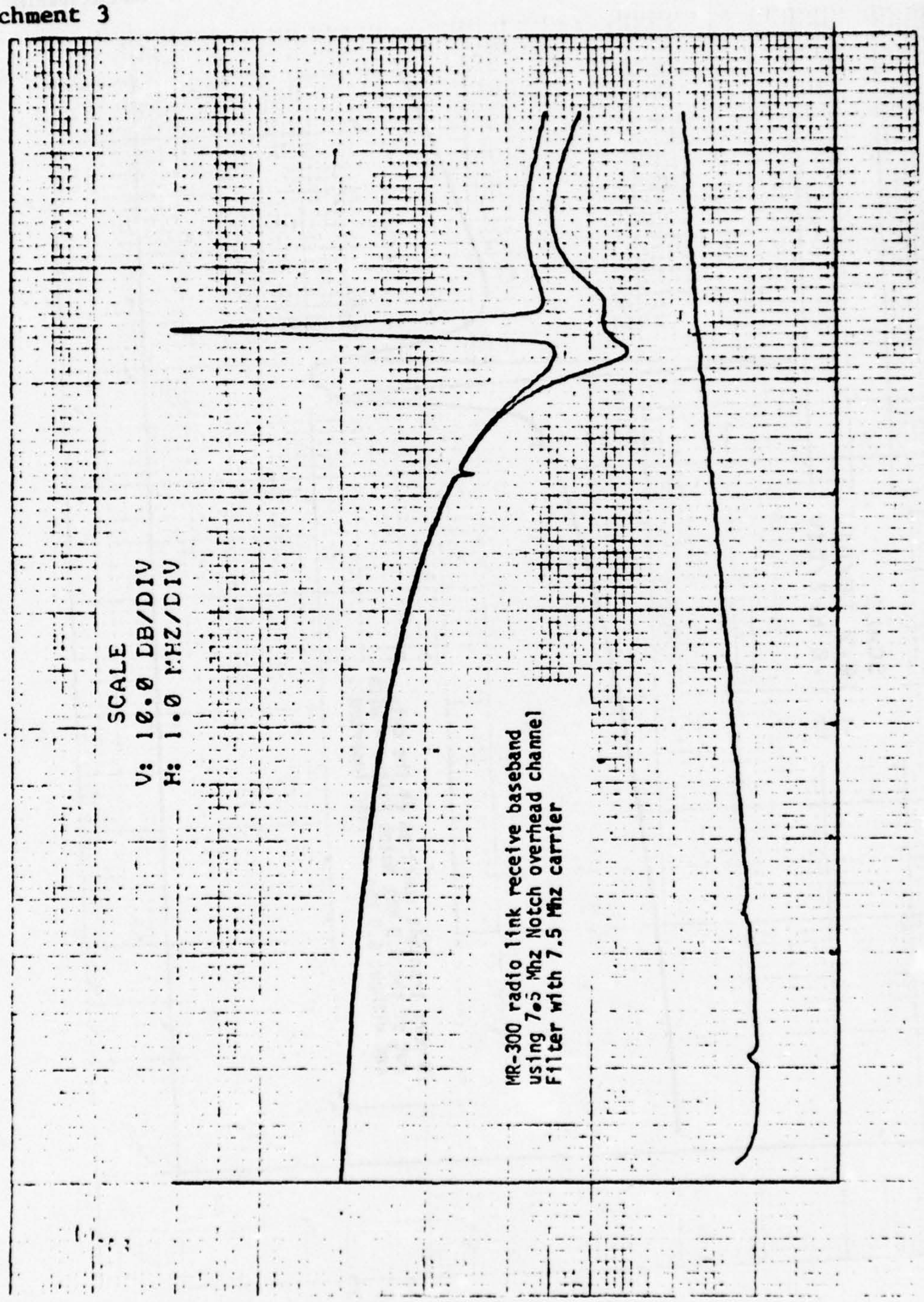

SCALE
V: 10.0 DB/DIV
H: 1.0 MHZ/DIV
MR-300 radio link receive baseband
using 7.5 Mhz Notch overhead channel
Filter with 7.5 Mhz carrier

Figure A3-49

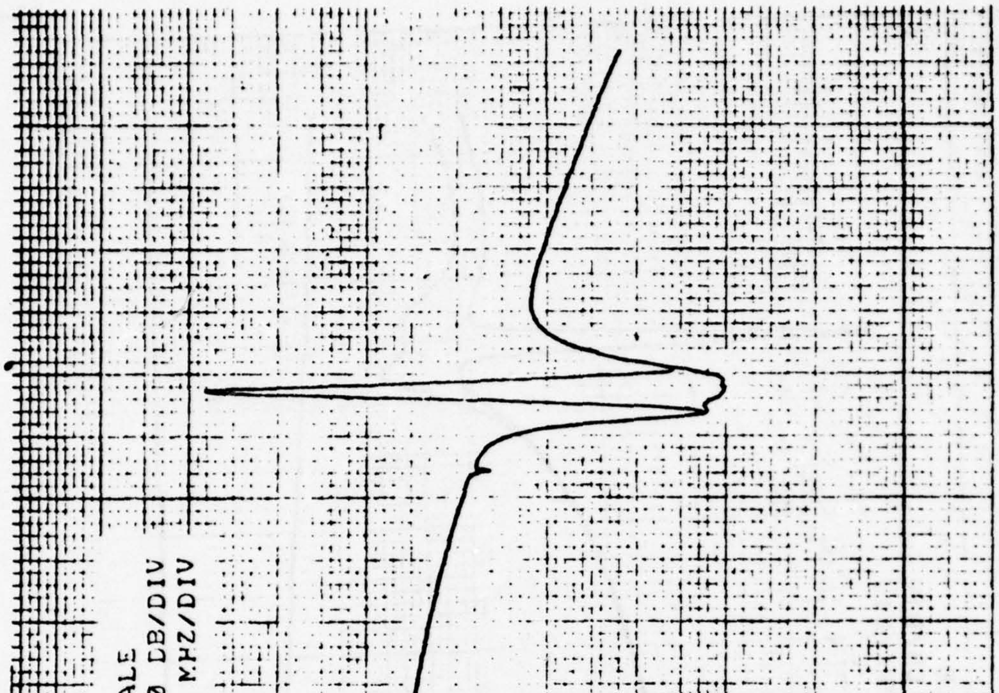

SCALE
V: 10.0 DB/DIV
H: 1.0 MHZ/DIV
8-port transmit spectrum at the output of the 6.9 Mhz Notch Filter - with and without 6.9 Mhz carrier inserted

Figure A3-50

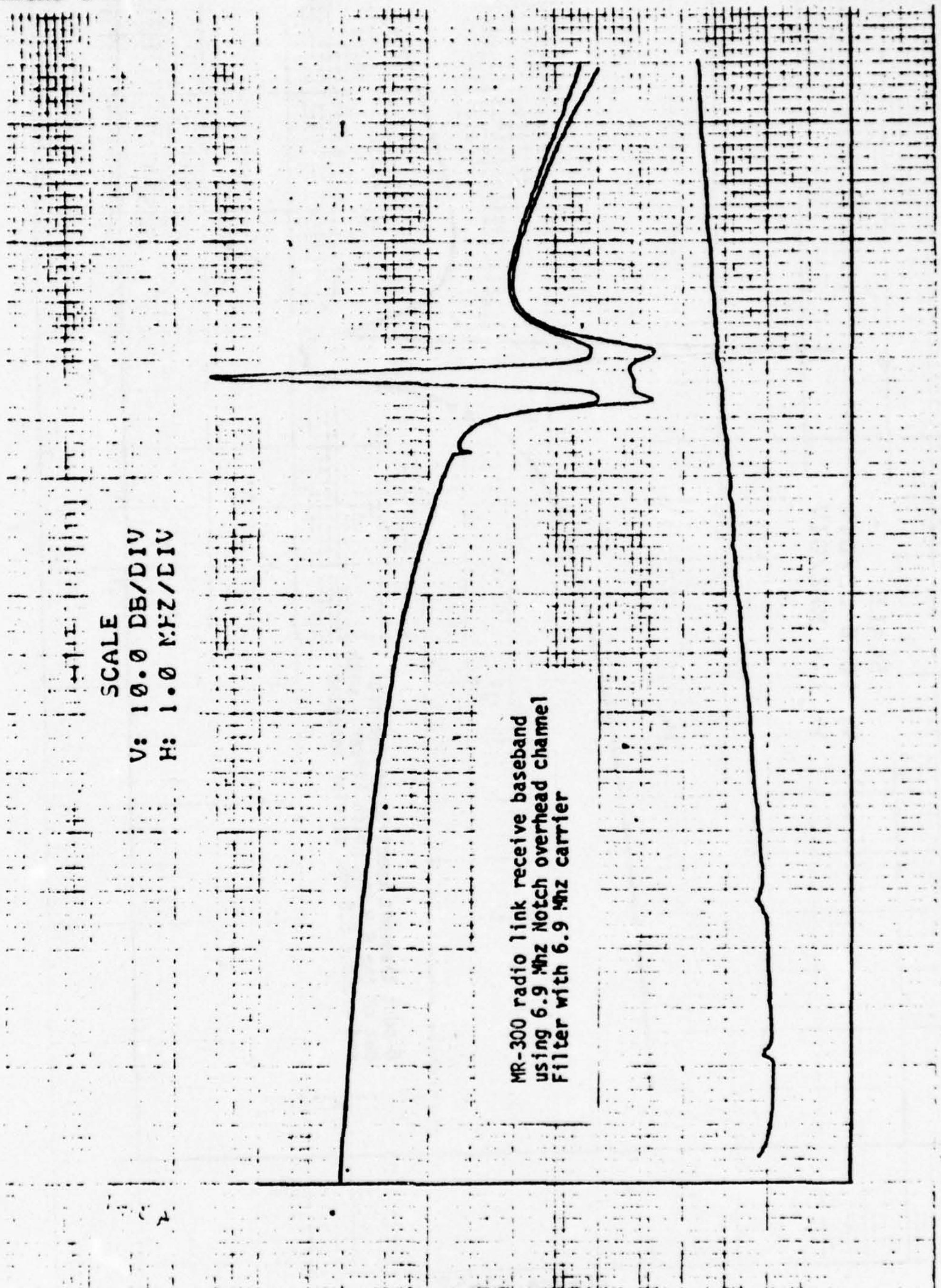

SCALE
V: 10.0 DB/DIV
H: 1.0 MHZ/DIV
MR-300 radio link receive baseband
using 6.9 Mhz Notch overhead chamel
Filter with 6.9 Mhz carrier

Figure A3-51

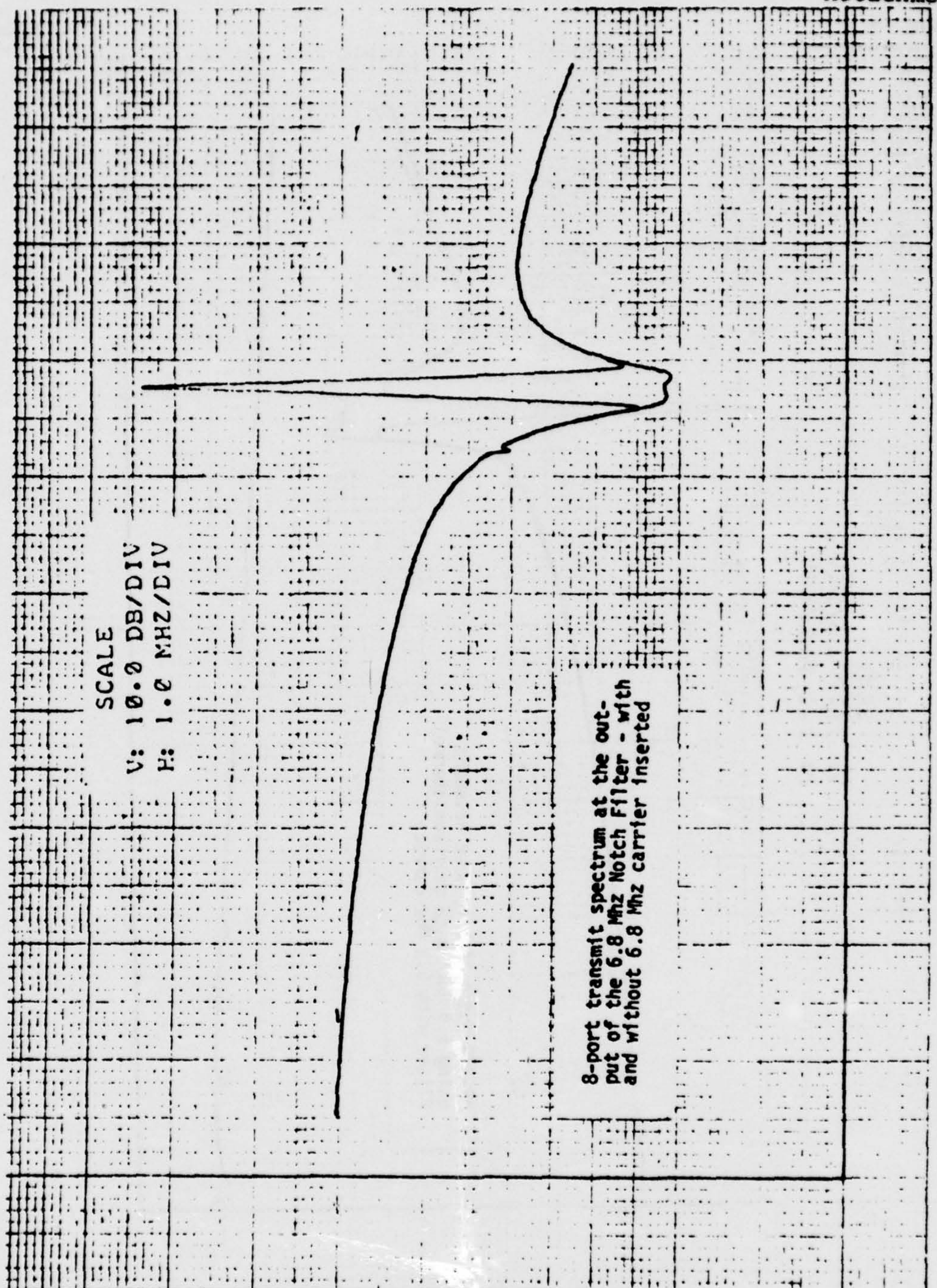

SCALE
V: 10.0 DB/DIV
H: 1.0 MHZ/DIV
8-port transmit spectrum at the output of the 6.8 Mhz Notch Filter - with and without 6.8 Mhz carrier inserted

Figure A3-52

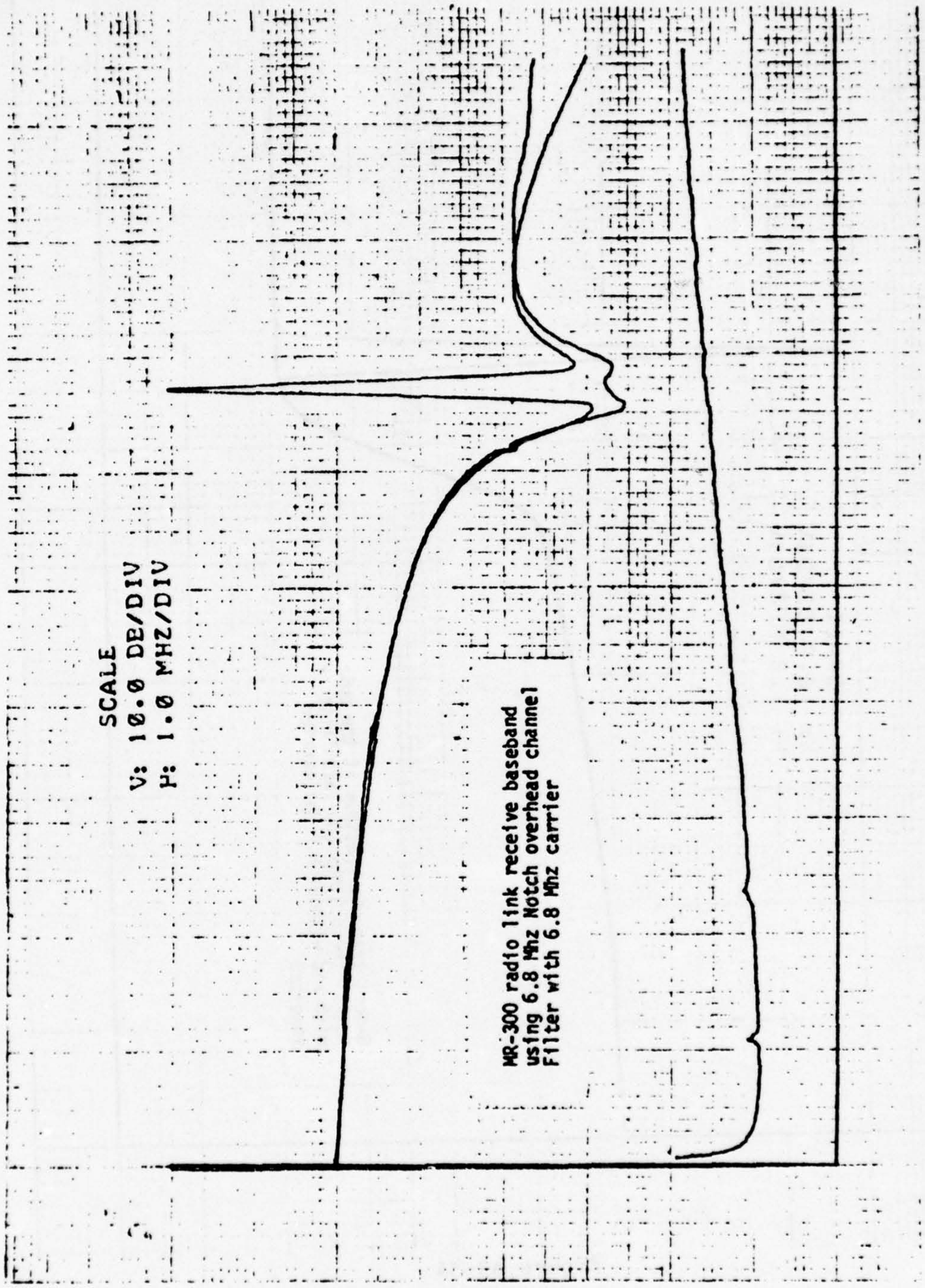

SCALE
V: 10.0 DB/DIV
H: 1.0 MHZ/DIV
MR-300 radio link receive baseband
using 6.8 Mhz Notch overhead channel
Filter with 6.8 Mhz carrier

Figure A3-53

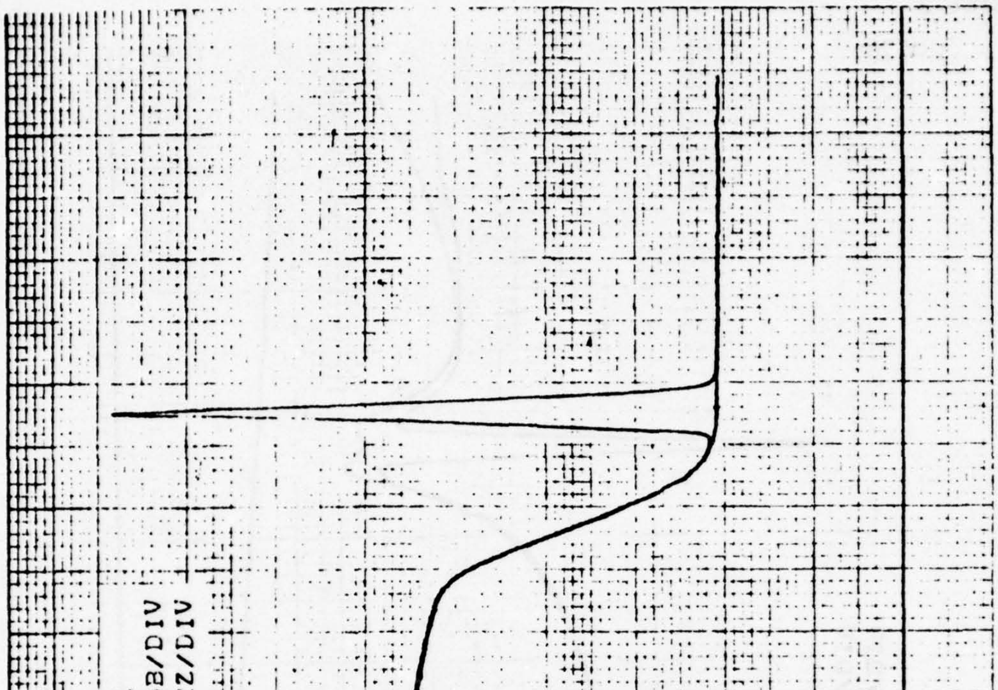

SCALE
V: 10.0 DB/DIV
H: 1.0 MHZ/DIV
8-port transmit spectrum at the output of the 5.5 Mhz Low Pass Filter - with and without 6.8 Mhz carrier inserted

Figure A3-54

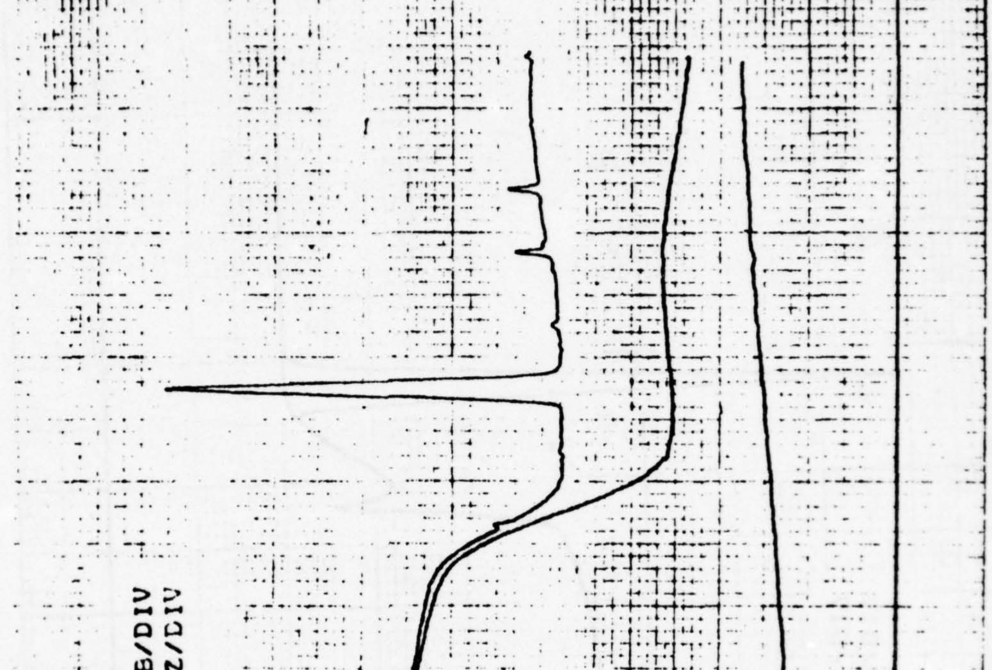

SCALE
V: 10.0 DB/DIV
H: 1.2 MHZ/DIV
MR-300 radio link receive baseband
using 5.5 Mhz Low Pass overhead
channel Filter with 6.8 Mhz carrier

Figure A3-55

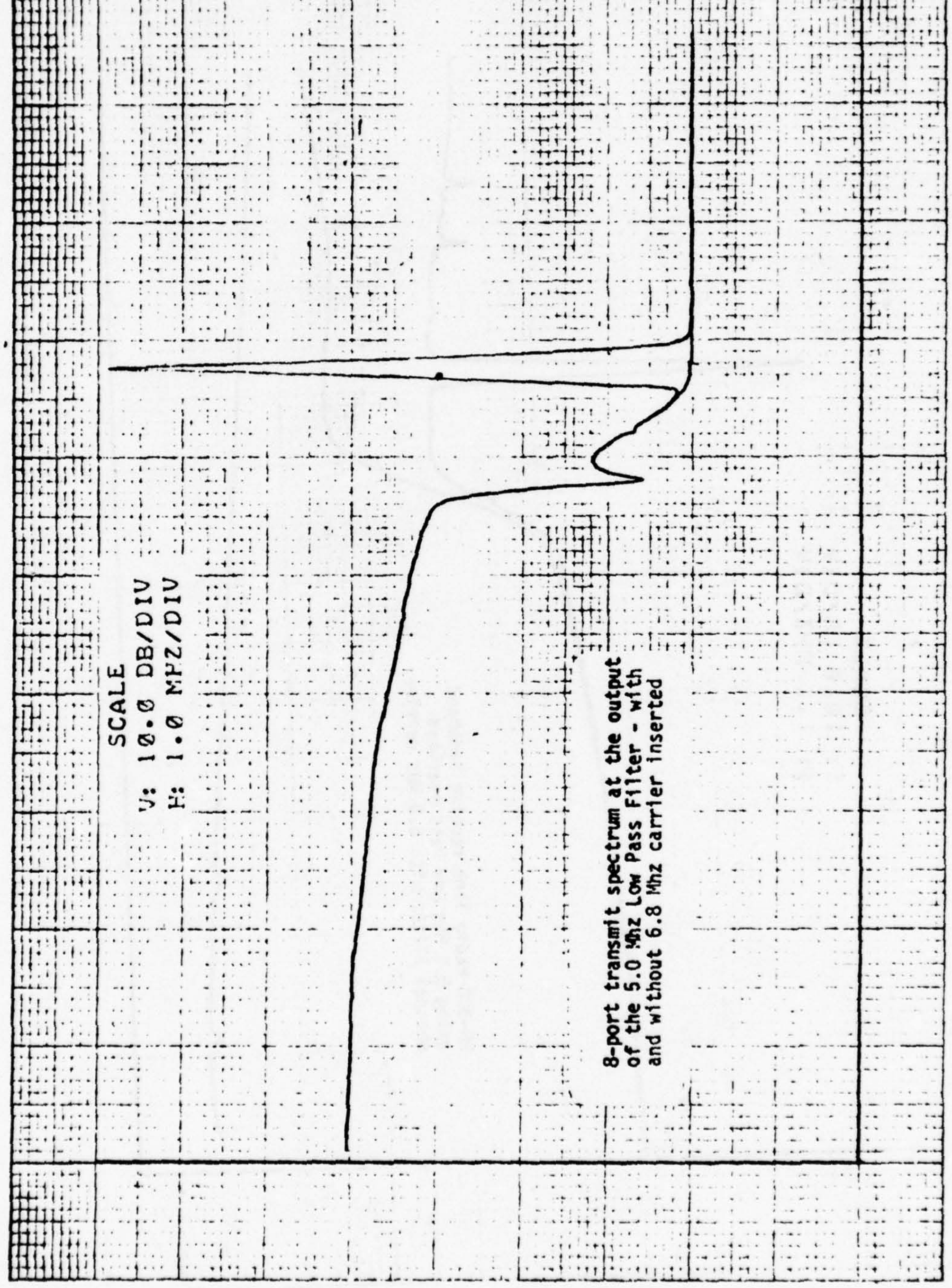

SCALE
V: 10.0 DB/DIV
H: 1.0 MHZ/DIV
8-port transmit spectrum at the output of the 5.0 Mhz Low Pass Filter - with and without 6.8 Mhz carrier inserted

Figure A3-56

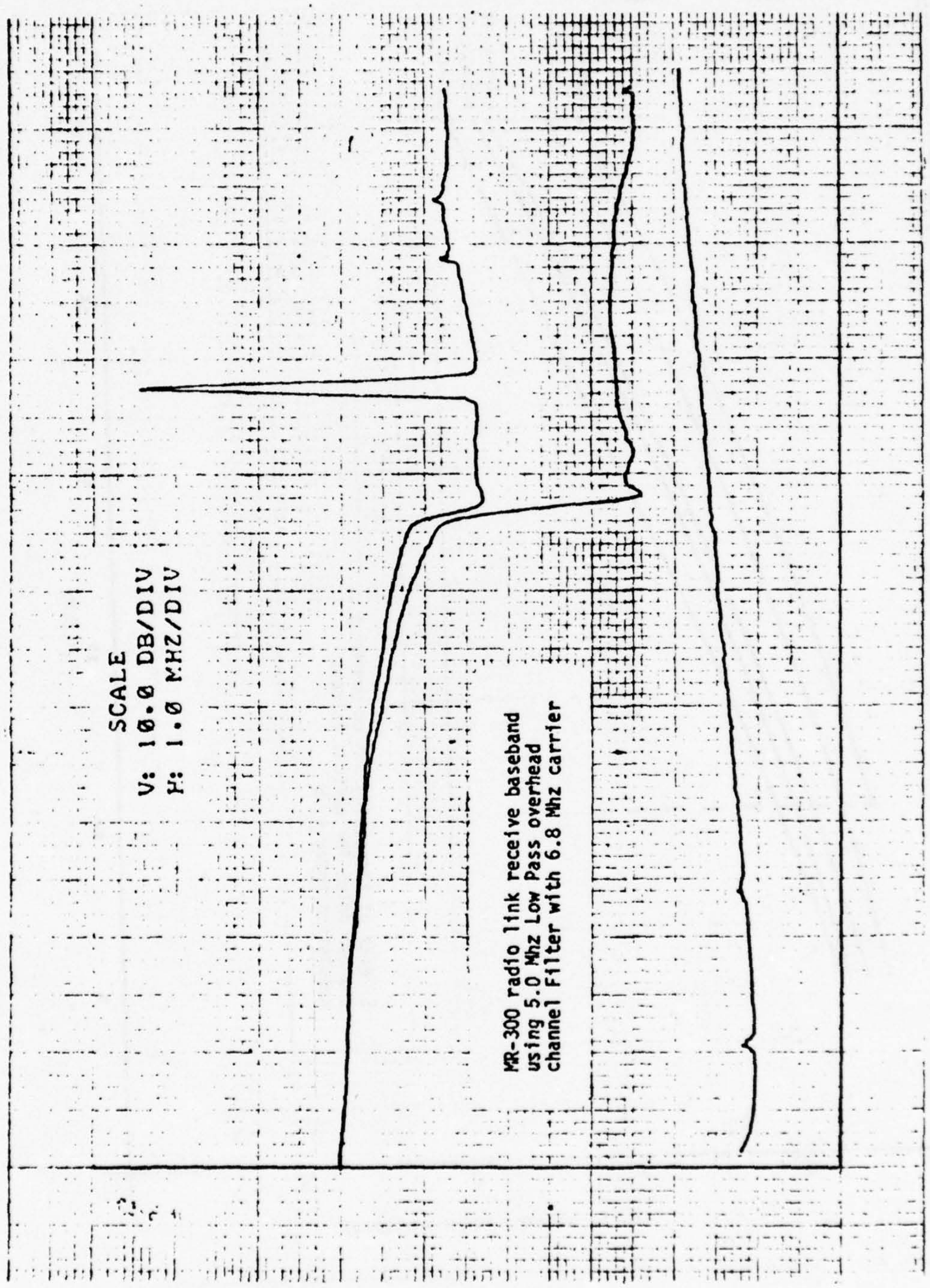

SCALE
V: 10.0 DB/DIV
H: 1.0 MHZ/DIV
MR-300 radio link receive baseband
using 5.0 Mhz Low Pass overhead
channel Filter with 6.8 Mhz carrier

Figure A3-57

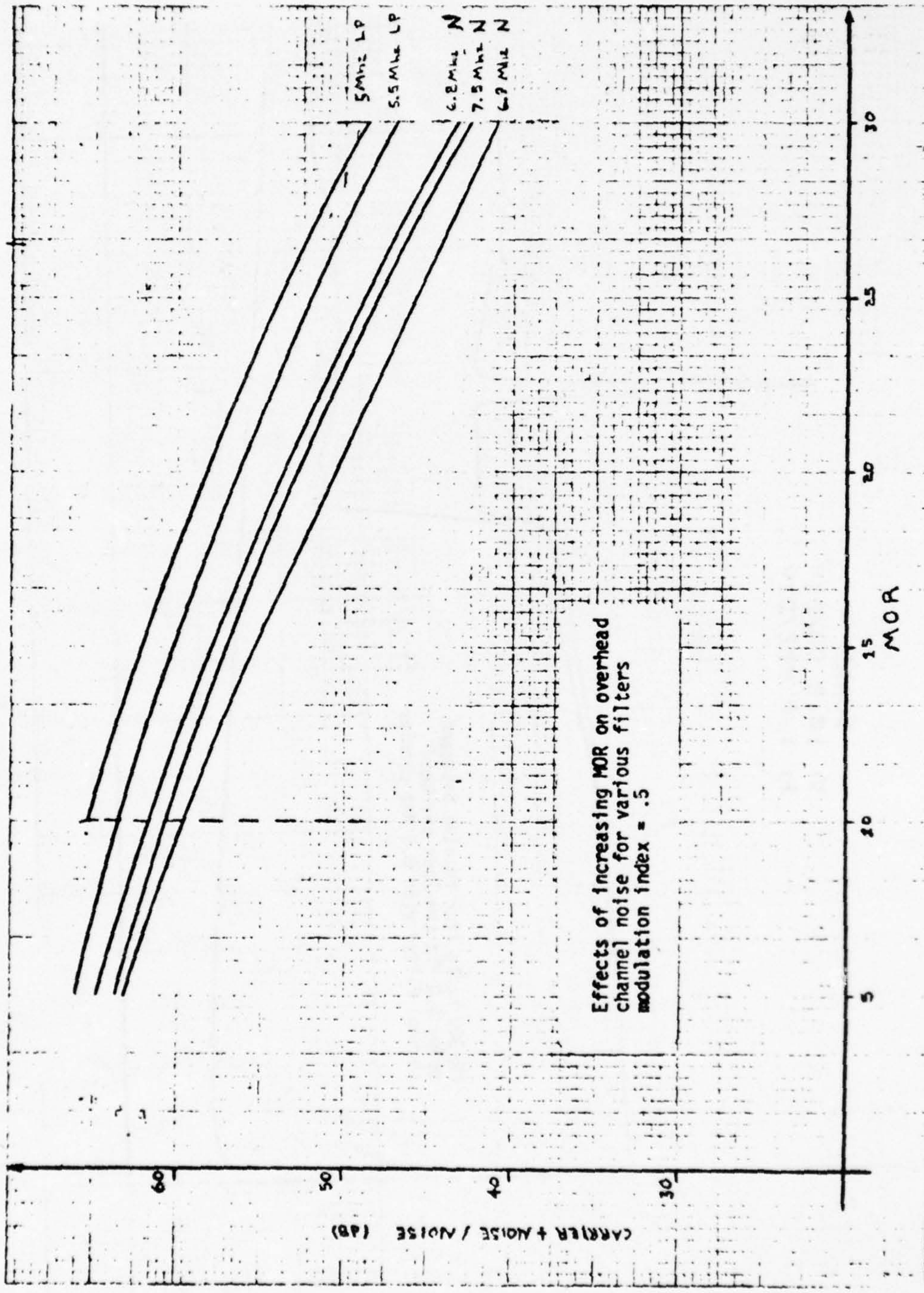

5 MHz LP
5.5 MHz LP
Effects of increasing MOR on overhead channel noise for various filters modulation index = .5
MOR
5
10
15
20
25
30
CARRIER + NOISE / NOISE (dB)
60
50
40
30

Figure A3-58

was counterbalanced by severe distortion of the TDM signal, as shown in Figures A3-22 and 3-27b.

3-5. Conclusions. The investigation into the effects of high end overhead channel on the TDM and the TDM's effects on the overhead channels are summarized as follows:

a. With the filters tested, it can be concluded that the low-pass filters, with the characteristics shown in Figures A3-14 through A3-28, severely degrade the TDM signal and are unacceptable for filtering the TDM signal. See particularly the eye pattern photographs in Figures A3-14 , 27, and 31.

b. The other filters tested, which were notch filters, as depicted in Figure A3-11, gave the best results. This filter was designed with group delay compensation in an attempt to reduce TDM signal degradation.

c. Bandwidth (RF) Efficiency. From the results of the RF frequency spectrum plots, Figures A3-33 to A3-38, it was shown that the transmitted TDM RF signal can just be contained within a 14 MHz bandwidth by the use of filtering and by keeping a multiplex to overhead channel ratio of less than 10 dB. Note that the 6.9 MHz filter was the only filter to contain the signal wholly within 14 MHz. The other 6.8 and 7.5 MHz did so within 15 MHz.

d. Greater improvements in RF transmit spectrum can be achieved by

decreasing the microwave radio peak-to-peak frequency deviation. For example, (illustrated in Figures A3-39 and A3-40) using the 7.5 MHz notch filter the power level at the 14 MHz bandwidth limits decreases from -20 dB for a modulation index of 0.5 to -30 dB for a modulation index of 0.3. However, this improvement is obtained at the expense of signal degradation. Figures A3-46 and A3-47 show the degree of signal degradation, as recorded by the meter deflection of the degradation monitor, versus radio signal level for decreasing modulation index. From these curves it is apparent that at good receive signal level (-48 dBm), the incremental change in degradation due to the overhead channel for a modulation index of 0.5 is approximately 16%, while that for a modulation index of 0.3 is 15%. At poor receive-signal level (-70 dBm), overhead channel degradation is 12% for a modulation index 0.5, and only 1% for a modulation index of 0.3. However, absolute degradation, both with and without the overhead channel filters and at a receive-signal level of -70 dBm, the modulation index of 0.3 records approximately 90% degradation, while 0.5 records only 62%. From this it can be concluded that decreasing the modulation index improves spectrum occupancy but at the expense of degrading the TDM signal overall. Noise measurements in a 200 KHz slot provided by the overhead channel filters gave the following information:

(1) Excluding the loss pass filters, the 6.8 MHz notch filter with characteristics shown in Figure A3-52 exhibited the best carrier-to-noise ratio over the multiplex to overhead channel ratio range of 10 dB to 30 dB.

(2) Noise power in the overhead channel position of the received baseband spectrum averaged approximately 6 dB higher than the transmitted

baseband spectrum. This noise power is the sum of the system's thermal noise and the microwave radio intermodulation power falling in the overhead channel bandwidth.

EFFECTS OF SIGNAL LEVEL VARIATION ON TDM PERFORMANCE

4-1. Objective. The test objectives were to determine the effects of TDM receive signal level variations on BER for various values of S/N ratio (peak-to-RMS) and determine the effects of AGC action on BER.

4-2. Discussion. While performing BER measurements with VICOM 8-port 4000 series TDM equipment, it was observed that small (1 dB) variations in the TDM receive input level caused order of magnitude changes in BER. Investigation of the TDM received signal under high noise conditions indicated that the 3 level partial response waveform at the 3 level test point (4090-02 interface unit) was reduced in amplitude by the AGC amplifier. The AGC circuit is a peak detector whose output controls the gain of the AGC amplifier. Under increased noise conditions the peak detector responds to the high noise peaks and reduces the gain of the AGC amplifier. The result of this action is a reduction in signal amplitude to the 3 level comparator circuits used in decoding the 3 level partial response waveform. A reduction in signal level in the decoder has the same relative effect as increasing the slicing levels in the decoding process. This places the slicers at other than optimum levels for decoding under degraded signal conditions. These procedures described below were used to determine the effects of this action.

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TEST ENGINEER: Mr. David A. Lindberg

4-3. Test Procedures.

a. The equipment was configured as shown in Figure A4-1.

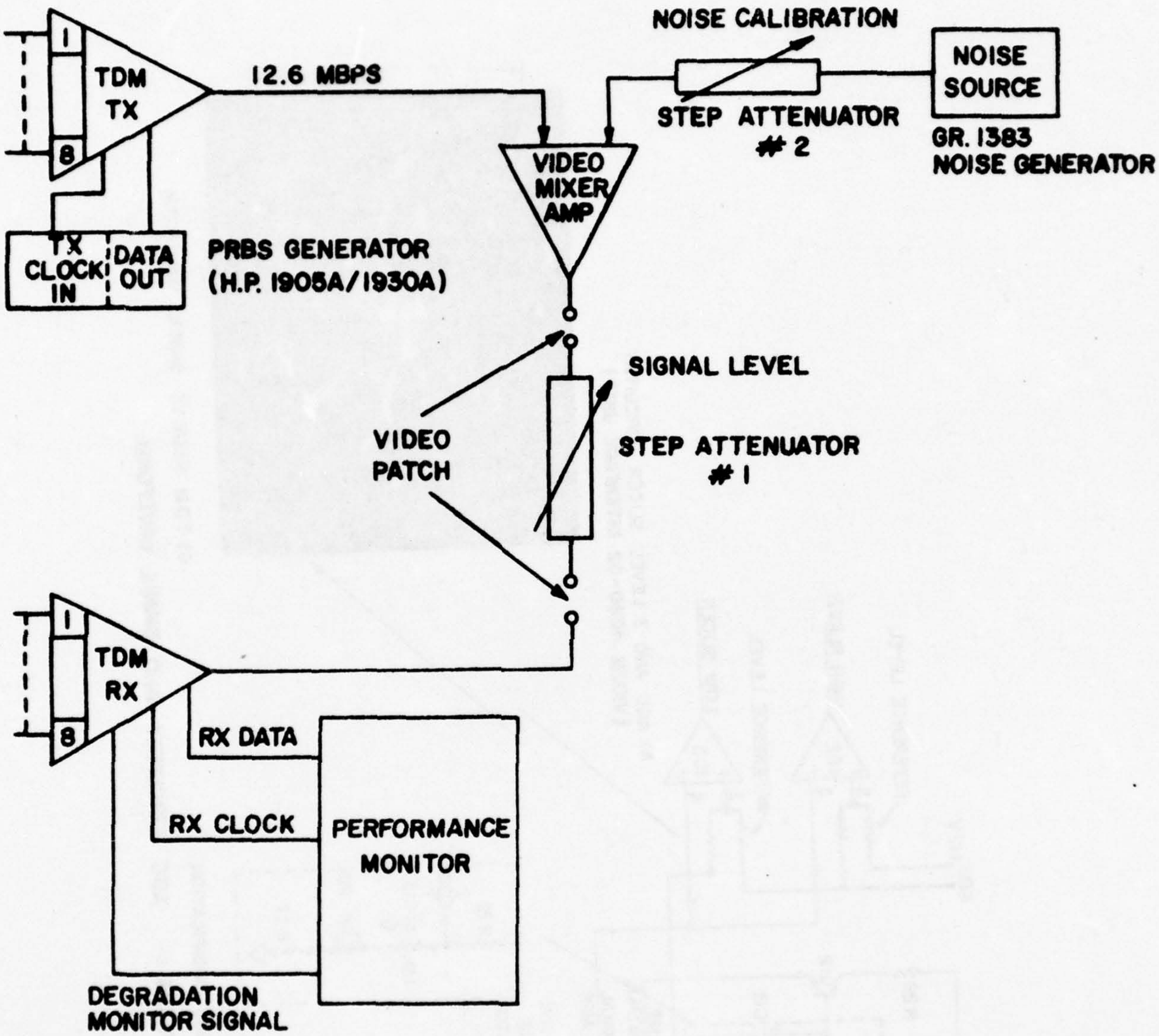
b. S/N vs BER curves were obtained using the noise calibration equipment, with attenuator #1 set at 10 dB.

c. Step 2 was repeated for attenuator #1 settings of 12, 11, 9, 8, 7, 6, and 5 dB, which corresponded to TDM receive levels from -2 dB to +6 dB relative to 1.0 Vp-p.

d. The VICOM 4090-02 card was then modified as shown in Figure A4-2b. This modification was done so that the AGC control voltage (Figure A4-2a) could be held constant. This then allowed the 3 level signal amplitude applied to the comparator circuit to the held constant for variations in S/N.

e. Step 2 was repeated for attenuator #1 settings of 12, 11, 10, 9, and 8 dB.

f. The resultant curves for BER vs TDM receive signal level for each value of S/N were plotted.



TDM RECIEVE SIGNAL VARIATION
MEASUREMENT CONFIGURATION

Figure A4-1

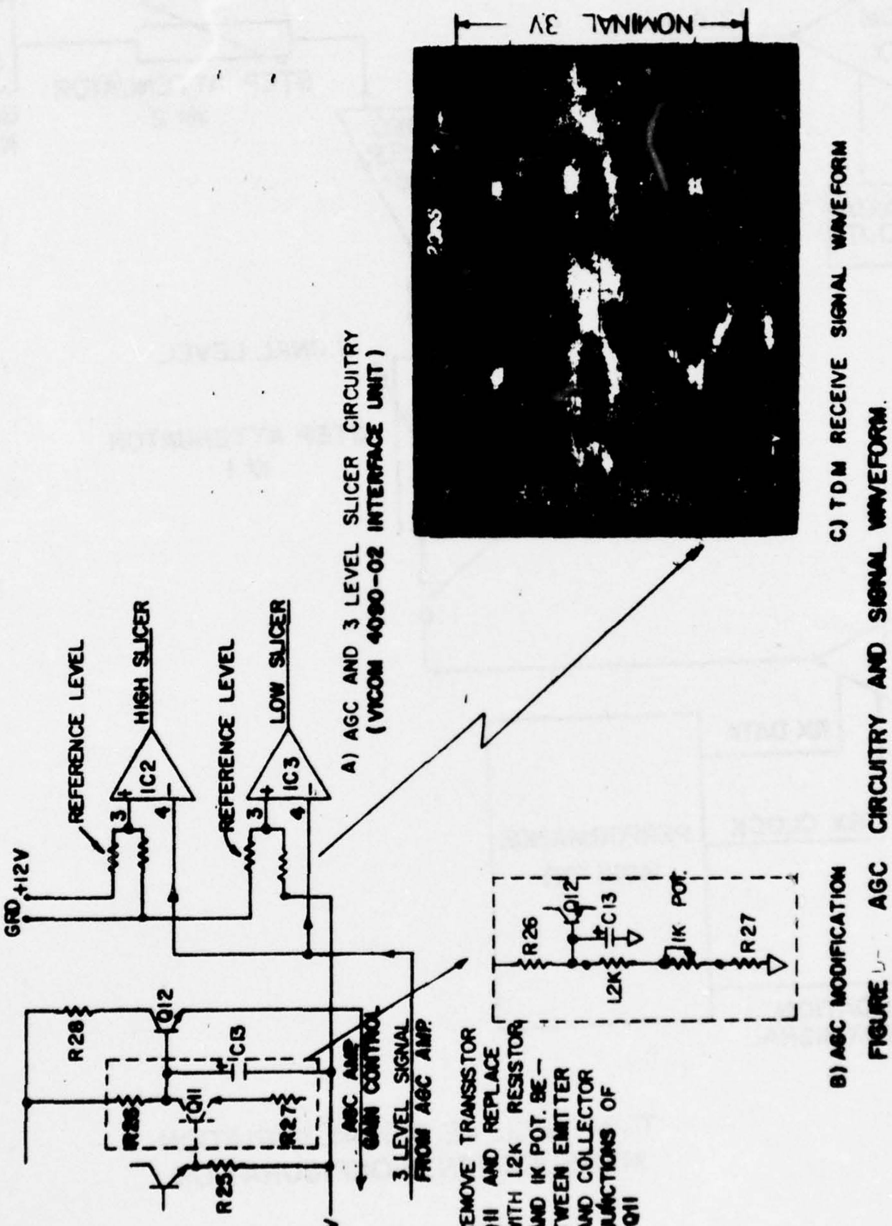

NOMINAL 3V
GRD
+12V
REFERENCE LEVEL
HIGH SLICER
REFERENCE LEVEL
LOW SLICER
IC2
IC3
R28
Q12
C13
R26
Q11
R27
R25
-6V
AGC AMP GAIN CONTROL
3 LEVEL SIGNAL FROM AGC AMP
A) AGC AND 3 LEVEL SLICER CIRCUITRY (VICOM 4090-02 INTERFACE UNIT)
NOTE: REMOVE TRANSISTOR Q11 AND REPLACE WITH 12K RESISTOR AND 1K POT. BETWEEN EMITTER AND COLLECTOR JUNCTIONS OF Q11
12K
1K POT.
B) AGC MODIFICATION
C) TDM RECEIVE SIGNAL WAVEFORM
FIGURE AGC CIRCUITRY AND SIGNAL WAVEFORM

Figure A4-2

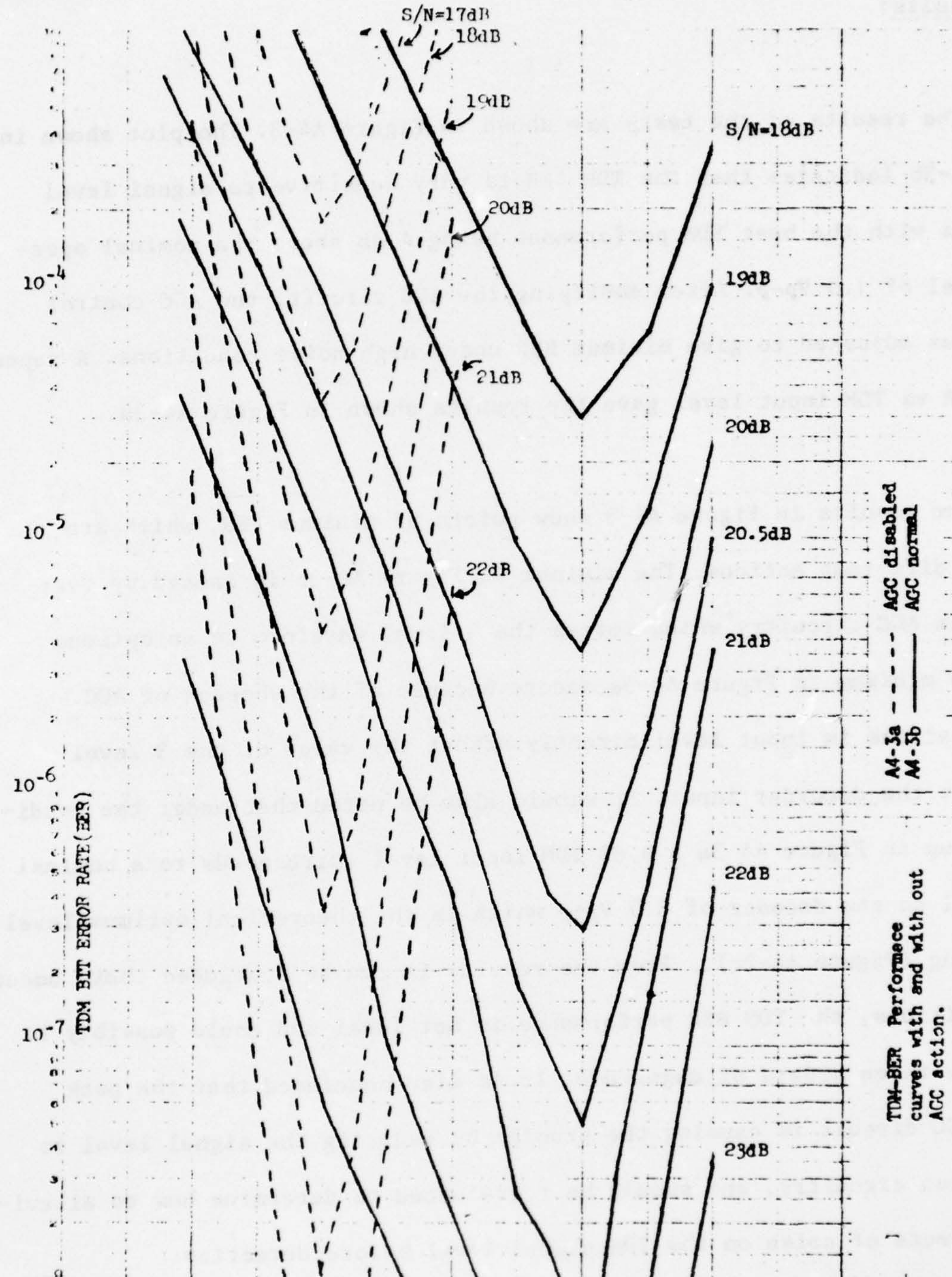

S/N=17dB
18dB
19dB
S/N=18dB
20dB
19dB
21dB
20dB
20.5dB
22dB
21dB
22dB
23dB
TDM BIT ERROR RATE(BER)
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
-2dB
0dB
($1.0V_{p-p}$)
+2dB
+4dB
+6dB
TDM RECEIVE INPUT LEVEL IN dB
A4-3a - - - AGC disabled
A4-3b ——— AGC normal
TDM-BER Performece curves with and with out AGC action.

Figure A4-3

4-4. Results:

a. The results of the tests are shown in Figure A4-3. The plot shown in Figure A4-3b indicates that the TDM BER is very sensitive to signal level variations with the best TDM performance being 4 dB above the nominal operating level of 1.0 Vp-p. After modifying the AGC circuit, the AGC control voltage was adjusted to give minimum BER under high noise conditions. A repeat of the BER vs TDM input level gave the results shown in Figure A4-3a.

b. The results in Figure A4-3 show points of minimum BER, which are caused by different actions. The minimum in Figure A4-3b is caused by overdriving the AGC circuitry which forces the 3 level waveform to an optimum level; the minimum in Figure A4-3a occurs because of the absence of AGC. Thus, variations in input level directly affect the value of the 3 level waveform at the decorder input. It should also be noted that under the conditions set up in Figure A4-3a a 0 dB TDM input level corresponds to a nominal input level to the decoder of 3.0 Vp-p which is the theoretical optimum level for decoding (Figure A4-2c). From the results it can be concluded that, under noise conditions, the TDM BER performance is not ideal and could possibly be improved by three orders of magnitude. It is also concluded that the peak detector AGC circuit is causing the problem by reducing the signal level to the detection circuitry, and should be reevaluated to determine how to alleviate the effects of noise on the TDM signal level before detection.

SYSTEM PERFORMANCE MONITORING EQUIPMENT CONFIGURATION DESCRIPTION

5-1. General.

a. The system performance monitoring equipment in the AFCS PCM/TDM Test Bed is the basis for the aquisition of most of the data from the prototype digital transmission system. Since the microwave radio links have been the principle determining factor of end-to-end system performance, the performance monitors are oriented towards the transmission channel (including the radios).

b. The performance monitor equipment is designed to provide information and data concerning:

(1) The performance of the radios, TDMs, and overhead channels as a function of receive signal level.

(2) The characteristic performance of the 3-level partial response signalling technique used by the VICOM TDMs in the presence of transmission channel perturbations.

(3) The ability of various degradation monitoring techniques to respond to increases in overall transmission channel degradation.

(4) The resolution and dynamic range of the various degradation monitors.

(5) The effects of increasing levels of bit error rate (BER) on the

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TEST ENGINEER: Capt Carl Reuter

system components (for example, the CY-104s, TDMs, and repeaters), as well as to equipment such as modems that may be operated over the PCM/TDM system.

(6) The ability of all the system equipment (especially the microwave radios) to provide satisfactory communications service in a digital system.

c. To meet these objectives several system/equipment parameters are measured:

(1) Receiver receive-signal level.

(2) Receiver baseband signal-plus-noise level.

(3) Receiver baseband loaded noise level.

(4) Degradation monitor outputs.

(5) TDM phase-locked loop voltages.

(6) TDM AGC voltage (see below).

(7) High speed and T1 BER.

(8) Overhead channel (orderwire) idle channel noise.

(9) Other data as applicable for specific tests.

d. Of these parameters, six were recorded continuously on a 6-channnel strip chart recorder, and BER was measured when applicable. (The overhead channel idle channel noise measurements are described in chapter 2, paragraph 2-3, and Attachment 3.) The effects of T1 BER on VF channel performance are described in chapter 2, paragraph 2-2, and Attachment 2.)

e. Figure A5-1 shows the system equipment configuration used to collect

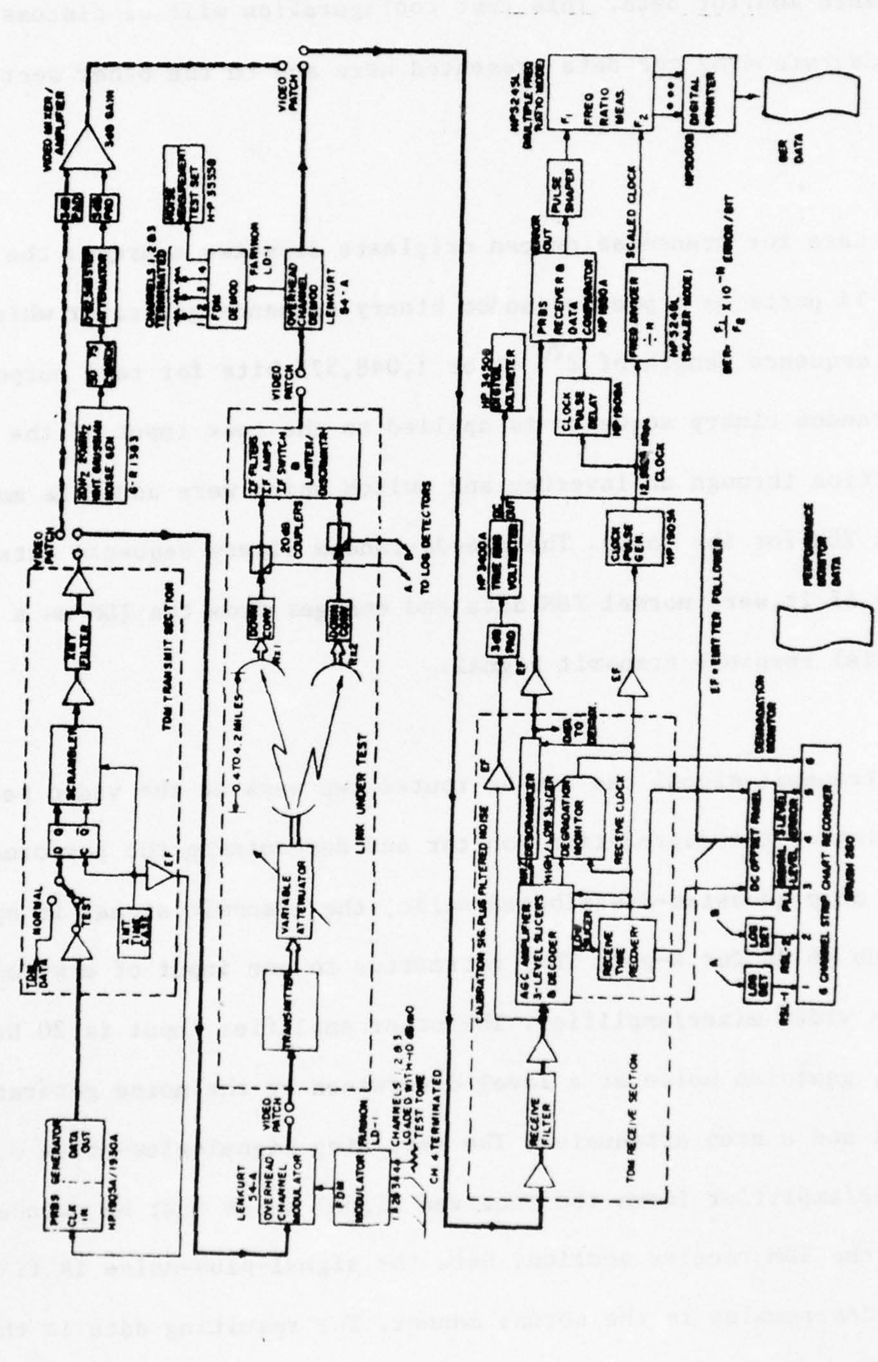

Figure A5-1

the performance monitor data. This test configuration will be discussed to assist in understanding the data presented here and in the other sections of this report.

f. The data for transmission can originate from two sources: the normal multiplexed T1 ports or a pseudo-random binary sequence generator which provides a bit sequence length of 2^{20} -1 or 1,048,575 bits for test purposes. The pseudo-random binary sequence is applied to the test input of the TDM transmit section through an inverter and switch which were added as modifications to the TDM for the tests. The pseudo-random binary sequence data is processed as if it were normal TDM data and emerges from the TDM as a $1V_{p-p}$ 3-level partial response transmit signal.

g. The transmit signal can now be routed two ways at the video patch. For calibration of the degradation monitor and determining the performance of the TDM with only gaussian-distributed noise, the transmit signal is applied through a 3 dB (6 dB for 4-port TDM) attenuator to one input of a wideband, variable gain video mixer/amplifier. The other amplifier input is 20 Hz to 20 MHz white, gaussian noise at a level determined by the noise generator level control and a step attenuator. The resulting signal-plus-noise output from the mixer/amplifier forms the received signal which must be patched to the input of the TDM receive section. Here the signal-plus-noise is filtered, decoded, and descrambled in the normal manner. The resulting data is then brought out of the TDM and, with receive clock, applied (through a pulse

shaper) to the F_1 input of a frequency counter operated in its multiple frequency ratio mode. The F_2 input to the counter is from a second frequency counter which is being used as a received clock frequency divider (scaler mode). The first counter then displays the bit error rate (BER) multiplied by the divider counter scale factor (for example, 10^1, 10^2, ... 10^N). The BER is then $\frac{F_1}{F_2} \times 10^{-N}$ errors/bit. For increased BER accuracy a higher ratio multiplier is selected in the "ratio" counter. Doing so causes more scaled clock cycles to be required to gate the accumulation of errors off. Therefore, at a given error rate more errors are accumulated (by factors of ten), but the decimal point is automatically moved to the left on the counter display and so the BER reading remains the same. Note, however, that with increased numbers of errors the significant or confidence level in the reading increases, but the time required to acquire a reading also increases. These two factors must be weighed against each other when low values of BER are being measured.

h. In addition to the monitoring of BER a second output function at the receive TDM is the degradation monitor(s). At present there are two degradation monitors but only one has been available in a useable form to be used in the test conducted to date. This monitor was described in detail in HQ AFCS/EPES, DCS Operational Test and Evaluation of PCM/TDM Equipment (Richards-Gebaur AFB: HQ AFCS, 1973), pages 264-280, but has been modified since then. The new version, as a part of the VICOM 4023 "Receive Input" card, is shown in Figure A5-2. The degradation monitor circuit compares the receive recovered clock and

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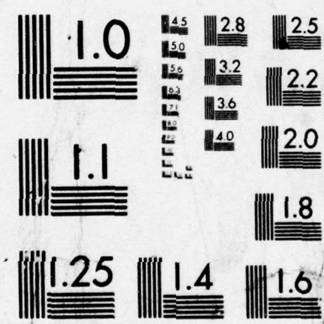

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

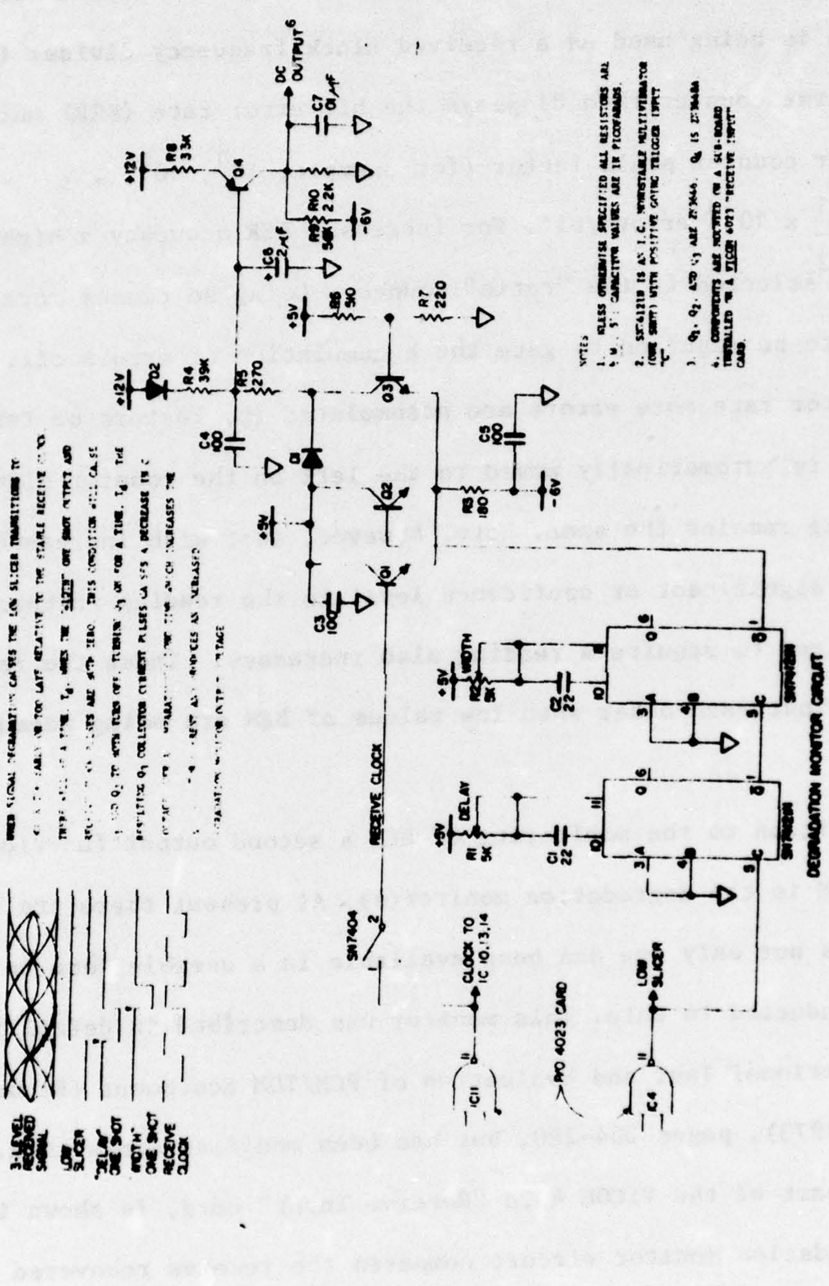
DEGRADATION MONITOR CIRCUIT
RECEIVE CLOCK
DC OUTPUT
DELAY
WIDTH
CLOCK TO IC 10,13,14
TO 4023 CARD
LOW SLICER
SN7404
SN74121

Figure A5-2

low slicer transition times to determine the degree of noise present on the received 3-level signal.

i. A third output from the receive TDM is the calibration signal. The calibration signal consists of the 3-level partial response signal-plus-noise after completion of the receive filtering and before the automatic gain control amplifier. It is at this point that the receive 3-level signal-to-noise (S/N) ratio is defined. Note that this ratio is the nominal peak signal-to-RMS noise. The calibration signal is applied to the input of a wideband true RMS voltmeter with a DC output which is connected to a digital voltmeter (DVM) to obtain greater precision and repeatability in making the calibration adjustments. The DC output is also connected to channel four of the 6-channel strip chart recorder to record the signal-plus-noise level when the TDM automatic gain control is disabled (see Attachment 4). The TDM phase locked loop (PLL) control voltage for the 12.5526 MHz receive clock was also monitored for the tests, as well as the integrated 3-level error density voltage (base of 014 on the VICOM 4023 "Receive Input" card). The PLL control voltage does not, however, respond significantly to noise, but is used to indicate that a bonafide TDM signal is being received at the "correct" data rate.

j. Figure A5-3 shows the calibration curves obtained using the calibration described above. Note that only channels 4, 5, and 6 of the strip chart recorder are shown. At the top of this figure is a plot of TDM BER versus S/N ratio with the TDM AGC disabled. The data obtained through the calibration

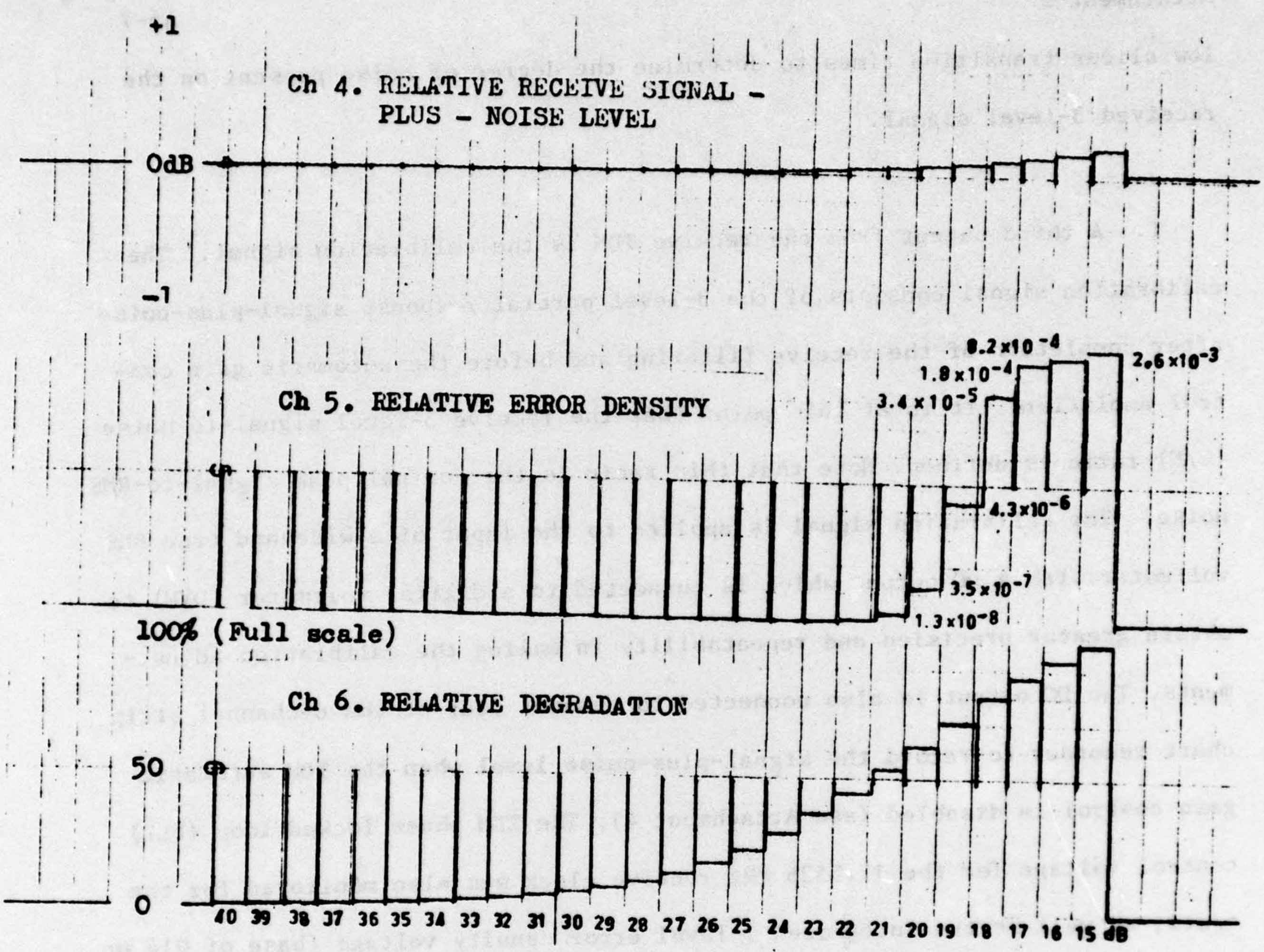

Fig. A5-3a. (above) CALIBRATION CURVES for PCM/TDM PERFORMANCE MONITORING EQUIPMENT CONFIGURATION. Curves are plotted versus TDM received peak signal-to - RMS noise ratios from "infinite" to 15dB (data begins at 40dB S/N ratio). Channel 5 (Relative Error Density) is the integrated voltage at the base of Q_{14} on the 4023 "Receive Input" card. This voltage decreases with increasing 3-level violation (error) rate. The values shown by each step are the corresponding BERs.

Fig. A5-3b. (opposite) PLOTS OF HIGH - SPEED (12.5526Mbps) BER versus RECEIVE SIGNAL - TO - NOISE RATIO (solid curve) and HIGH - SPEED BER versus DEGRADATION MONITOR OUTPUT (dashed curve).

Figure A5-3a

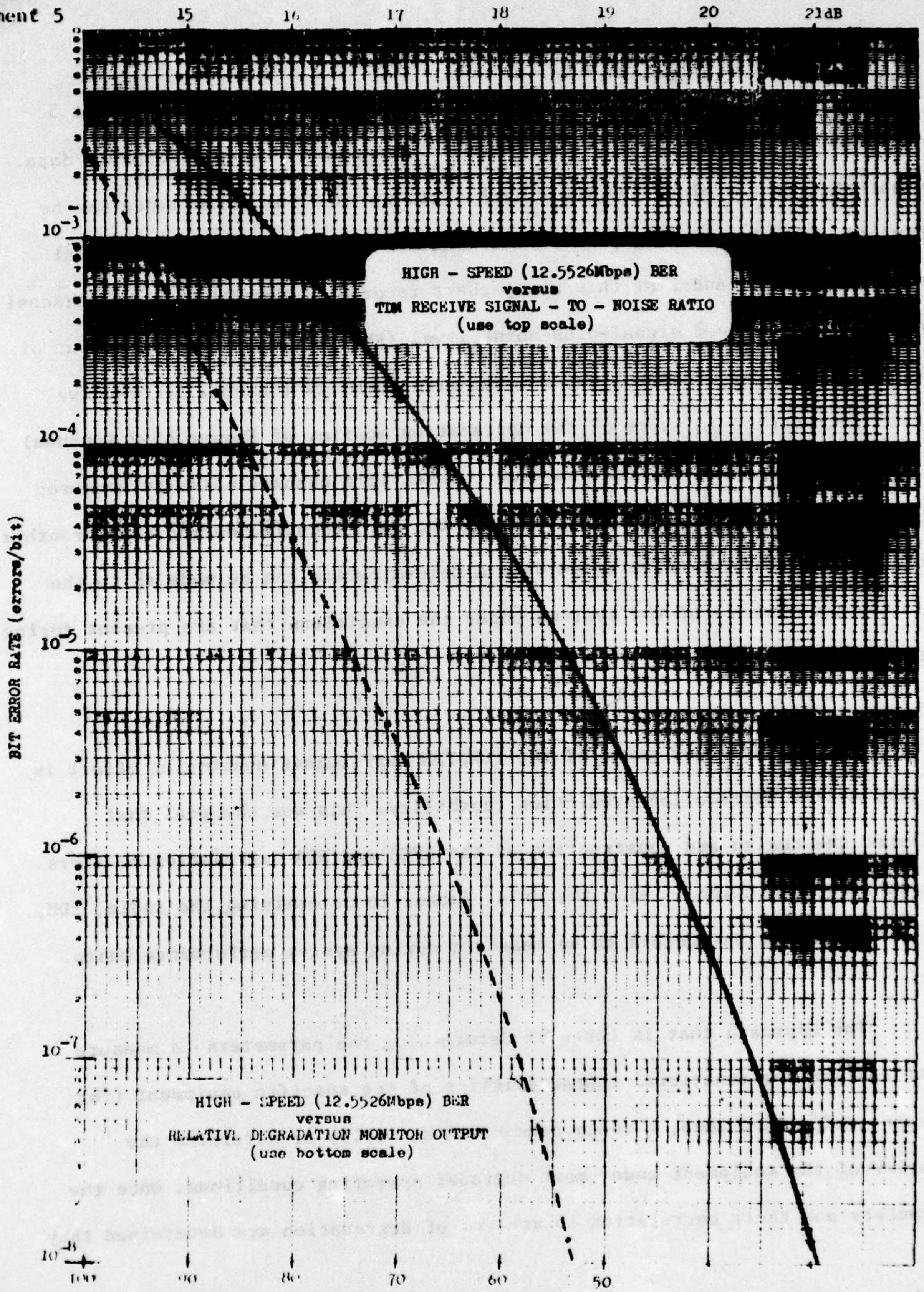
15
16
17
18
19
20
21dB
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
BIT ERROR RATE (errors/bit)
HIGH - SPEED (12.5526Mbps) BER
versus
TDM RECEIVE SIGNAL - TO - NOISE RATIO
(use top scale)
HIGH - SPEED (12.5526Mbps) BER
versus
RELATIVE DEGRADATION MONITOR OUTPUT
(use bottom scale)
100
90
80
70
60
50

Figure A5-3b

configuration is then used as a basis for comparison of link performance data. By patching in the microwave radio link, data on the link performance may be obtained. In this mode the performance monitors are receiver receive-signal level (channels 1 and 2 of this strip chart recorder), TDM PLL voltage (channel 3), baseband received signal-plus-noise level (RMS value measured at output of TDM receive filter - channel 4), 3-level error density (channel 5), receive signal degradation in terms of the degradation monitor of Figure A5-2 (channel 6), and BER. In addition, the overhead channel idle channel noise is measured as shown (see Attachment 3). By comparing the data acquired during link or other system tests with the calibration data a determination can be made as to the relative performance of the systems under the conditions that are present during the test or evaluation.

k. One of the major goals of the PCM/TDM performance monitoring effort is to gain a link degradation prediction capability. This was the goal that prompted the design and construction of the AFCS and NSA degradation monitors. Degradation prediction is also the major factor in determining the radio, TDM, and PCM equipment parameters to be measured during system performance tests.

l. The approach that is taken in determining the parameters to measure is to analyze the functional characteristics of the specific equipment (for example, radio) and then, through measurements, verify or determine the behavior of the equipment under most degraded operating conditions. Once the parameters and their correlation to sources of degradation are determined they

are then used for performance monitoring or rejected depending on the amount of predictive margin afforded. Having a continuous range of monitoring 3-level waveform distortion also allows a comparison of the quality of transmission that is not available by BER measurements (since there may be no errors occurring). Although not currently finalized, a technique for determining increases in the lower radio threshold point is being investigated. When available, this capability should enable a prediction of link degradation prior to any noticeable effects on the transmitted data and lead to corrective action before an actual service impairment occurs.

NOTES:

1. *Due to a minor procedural error the calibration curves given in the previously referenced HQ AFCS, 1973 test report (page 119) are not wholly correct. The calibration curves given here in Figure A5-3 supersedes the earlier published data.*
2. *In the HQ AFCS, 1973, test report it was stated that a degradation monitor was furnished by the National Security Agency for test and evaluation (page 113-114). This monitor was to be tested in a 12.5526 Mbps version as soon as the new unit was available. However, the 12.5526 Mbps version has only recently been completed and test results will therefore be included in the next test report.*

LIST OF DEFINITIONS

6-1. General. These definitions and abbreviations are applicable only to this particular test (text, tables and figures). Future tests will use the approved abbreviations contained in AFM 11-1, Volumes I and III and AFM 11-2.

A_i - availability of an item

$$A = \frac{MTBF_i}{MTBF_i + MRT_i}$$

A_s - availability of system

$$A_s = \frac{MTBF_s}{MTBF_s + MRT_s}$$

MRT_i - mean restoral time of an item

MRT_s - mean restoral time of a system

$MTBF_i$ - mean time between failures of an item

$MTBF_s$ - mean time between failures of a system

$MTTR_i$ - mean time to repair an item

$MTTR_s$ - mean time to repair a system

MWC - maintenance work center

N - number of items

P (A) - the probability of "A"

Q_i - the unreliability of an item (see R_i)

$$Q_i = \overline{1} - R_i$$

Q_s - the unreliability of a system (see R_s)

$$Q_s = \overline{1} - R_s$$

R_i - the reliability of an item. This is the probability that an item will operate satisfactorily for a given time.

$$R_i = EXP\ (\lambda_i t)$$

R_s - the reliability of a system.

$$R_s = EXP\ (\lambda_s t)$$

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TEST ENGINEER: Lt Warren Boxleitner

t - any time period of interest

λi - failure rate of an item

$$\lambda i = \frac{1}{MTBF_i}$$

λs - failure rate of a system

$$\lambda s = \frac{1}{MTBF_s}$$

6-2. MTTR vs Manning.

The purpose of the following discussion is to establish what manning levels results with various MTTR standards. In order to evaluate the relationship more easily, the MTTR has been divided into three components as shown below.

MTTR = MWT + MTT + MTTRS

These components are defined as follows:

MWT - Mean Waiting Time (This is defined as the average length of time during which the equipment is down and no maintenance personnel are available at the MCS).

MTT - Mean Travel Time (This is defined as the average time required to travel from the maintenance work center (MWC) to the site).

MTTRS - Mean Time to Repair on Site (This is the average time required to do "on site" equipment repairs).

In order to estimate the MTT, the following assumptions were made:

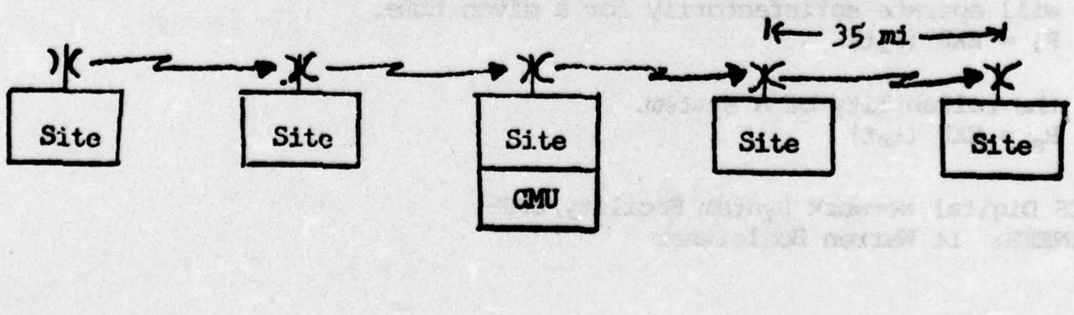
a. Failures were assumed to be random.

b. The distance between sites was assumed to be 35 miles.

c. The sites were assumed to be in a straight line.

d. The average rate at which the maintenance personnel travel was assumed to be 28 mph.

The diagram below illustrated the configuzation of the sites.



The table below illustrates that the value of the MTT is dependent on the number of sites for which the MWC is responsible.

If the MWC is responsible for the maintenance of:	Then the MTT will be:
1 site	0 hr
3 sites	0.83 hr
5 sites	1.5 hr

The value of the MWT depends not on the number of sites, but on the amount of time that maintenance personnel are available at the MWC.

If the MWC is manned:	Then the MWT will be:
24 hr/day	0 hr
16 hr/day	1.5 hr
8 hr/day	5 hr

All the previous components of the MTTR are compiled in the following table and the relationship to manning levels is shown.

No. of hrs CMU is manned	No. of sites CMU is responsible for	Personnel required at one CMU	MWT (hrs)	MTT (hrs)	MTTRS (hrs)	MTTR	Personnel required per 5 sites
24	1	12	0	0	1	1	60
~~16~~	~~1~~	~~8~~	~~1.5~~	~~0~~	~~1~~	~~2.5~~	~~40~~
~~8~~	~~1~~	~~4~~	~~5~~	~~0~~	~~1~~	~~6~~	~~20~~
24	3	13	0	.83	1	1.83	22
~~16~~	~~3~~	~~9~~	~~1.5~~	~~.83~~	~~1~~	~~3.33~~	~~15~~
~~8~~	~~3~~	~~6~~	~~5~~	~~.83~~	~~1~~	~~6.83~~	~~10~~
24	5	14	0	1.5	1	2.5	14
16	5	10	1.5	1.5	1	4	10
8	5	6	5	1.5	1	7.5	6

Those combinations that have both a larger MTTR and a requirement for more personnel than other possible combinations have a line through them and will be ignored. The exact number of personnel shown in the chart is correct only for the specific assumptions given previously; however, it is apparent that manning may be reduced a great deal, if one is willing to allow a slight increase in the MTTR.

1-3. Feasibility of the Maintenance Concept:

a. Assumptions. In order to establish the feasibility of the proposed maintenance concept, both reliability and maintainability figures of merit were calculated. These calculations were based on the following assumptions:

(1) All the assumptions in the preceding paragraphs are applicable.

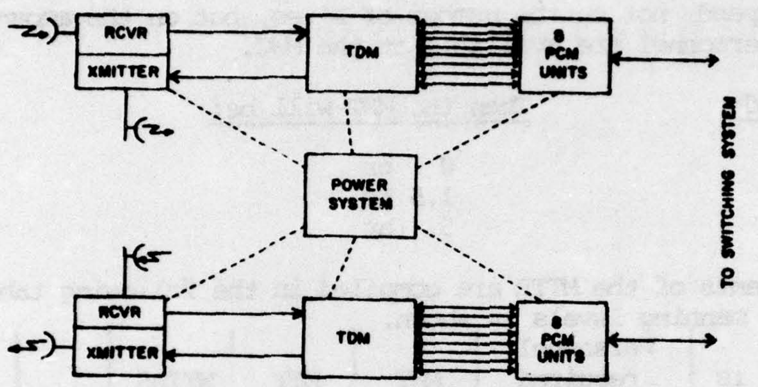
(2) The reference "system" is assumed to consist of 15 sites; 5 of which are through repeaters and ten of which have VF channel breakout.

(3) It is assumed that each primary radio unit should have one redundant backup unit.

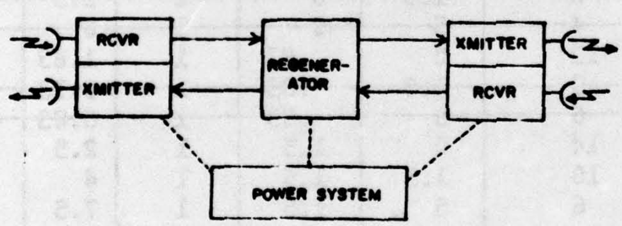
(4) It was assumed that each primary TDM unit would have one redundant backup unit.

(5) It was assumed that there would be two redundant PCM units per site to backup the primary PCM units at the site.

(6) The diagram below illustrates the equipment configuration that was assumed for sites with VF channel breakout.



(7) The following diagram illustrates the assumed configuration of equipment at a through repeater.



(8) The predicted MTBF for each type of equipment is given below:

(a) The MTBF of the PCM unit is predicted to be 4500 hr. This is based on a National Security Agency (NSA) study dated October 1972 which states that the anticipated MTBF for the CY-104 equipment is 4500 hr.

(b) The MTBF of the TDM unit is predicted to be 3500 hr. This prediction is also based on October 1972 NSA study.

(c) The MTBF of the radio unit is predicted to be 3000 hr. This is based on OCAMA/MMER estimates.

All formulas on which the following calculations are based are either found in the definitions or in the following paragraphs:

The degree of maintainability was established by comparing the maximum time required for maintenance action to the MTBF of all the sites for which the MWC is responsible. Under the constraints imposed by the maintenance concept, the maintenance personnel should be able to maintain at least one site per day. The maximum time required for maintenance action would therefore be 24 hours.

The MTBF of all sites for which the MWC is responsible is dependent on the number and type of sites involved.

The MWC was assumed to be responsible for 5 sites all with channel breakout. This case requires the most maintenance. The MTBF of all 5 sites taken together is found by using the following formula:

$$MTBF_s = \frac{1}{\sum_{i=1}^{N} \frac{1}{MTBF_i}}$$

b. Maintainability:

The following calculations give an indication of the maintainability of the assumed system, using the basic formula:

The MTBF of all the 18 PCM units at the site would be:

$$MTBF_{18\ PCM} = \frac{1}{\sum_{i=1}^{18} \frac{1}{4500}} = \frac{4500}{18} = 250 \text{ hr}$$

The MTBF of all 4 TDM units at the site would be

$$MTBF_{4\ TDM} = \frac{1}{\sum_{i=1}^{4} \frac{1}{3500}} = \frac{3500}{4} = 875 \text{ hr}$$

The MTBF of all 4 radio units at the site would be:

$$MTBF_{4\ radios} = \frac{1}{\sum_{i=1}^{4} \frac{1}{3000}} = \frac{3000}{4} = 750 \text{ hr}$$

The MTBF of the backup power system is to be 2 years (17520 hrs).

The MTBF of the entire site would be:

$$MTBF_{site} = \frac{1}{\frac{1}{250} + \frac{1}{875} + \frac{1}{750} + \frac{1}{17520}}$$

The MTBF of 5 of the above sites taken together would be:

$$MTBF_{5\ sites} = \frac{1}{\sum_{i=1}^{5} \frac{1}{153}} = \frac{153}{5} = 30.6\ hr$$

Thus, the longest time required for maintenance will be less than the average interval between demands for maintenance under the maximum workload conditions. If the number of sites was reduced or if some sites were through repeaters, the frequency of maintenance demands would decrease and the system would be even more maintainable.

c. Reliability. To establish the degree of reliability of the assumed PCM/TDM configuration, the probability of a system failure and the probability of the failure of a single site in one week were calculated.

(1) Reliability of the system:

The probability of 3 given PCM units having overlapping failures in one year (8760 hr) is found by using the following equation:

$$Q_{3\ items} = (1-e^{\frac{-8760}{MTBF_A}})(1-e^{\frac{-MTTR_A}{MTBF_B}})(1-e^{\frac{-MTTR_{A\ and\ B}}{MTBF_C}})$$

For the 3 PCM units $MTBF_A = MTBF_B = MTBF_C = 4500$ hr, $MTTR_A = 7.5$ hr (see chart in previous paragraph), and $MTTR_A = 1$ hr $= 8.5$ hr.

Therefore:

$$Q_{3\ PCM} = (1-e^{\frac{-8760}{4500}})\ (1-e^{\frac{-7.5}{4500}})\ (1-e^{\frac{-8.5}{4500}})$$

$$Q_{3\ PCM} = 2.69 \times 10^{-6}$$

At a site with channel breakouts there may be up to 18 PCM units. Thus, there are $\frac{18!}{3!\ (15!)}$ = 816 possible combinations of 3 PCM units at a site. The probability of any 3 of the 18 PCM units failing is approximately:

$$Q_{any\ 3\ PCM} = (2.69 \times 10^{-6})\ (816) \approx 2.2 \times 10^{-3}$$

The probability of a primary TDM *and* its standby failing in one year is found by using the following equation:

$$Q_2 \text{ items} = (1-e^{\frac{-8760}{MTBF_A}})\ (1-e^{\frac{-MTTR_A}{MTBF_B}}) \qquad MTTR_A = 7.5 \text{ hr} \qquad MTBF_A = MTBF_B = 3500 \text{ hr}$$

Therefore

$$Q_2 \text{ TDM} = (1-e^{\frac{-8760}{3500}})\ (1-e^{\frac{-7.5}{3500}}) = 1.97 \text{ X } 10^{-3}$$

Since there are two TDM redundancy pairs at a site with channel breakouts, the probability of either redundancy pair failing is approximately equal to:

$$Q_{\text{either TDM pair}} = (2)\ (1.97 \text{ X } 10^{-3}) \approx 3.93 \text{ X } 10^{-3}$$

It has been assumed there would be two redundancy pairs of radios at either a through repeater or a site with channel breakout. The same general formula as above can be used to find the probability of either radio redundancy pair failing in one year:

$$Q_{\text{either radio pair}} = (2)\ (1-e^{\frac{-8760}{3000}})\ (1-e^{\frac{-7.5}{3000}})$$

$$Q_{\text{either radio pair}} \approx 4.72 \text{ X } 10^{-3}$$

No predicted MTBF for the regeneration equipment was available; however, it was felt that the regeneration equipment would be at least as reliable as the radio equipment. The unreliability of the regenerator equipment over a year would therefore be approximately:

$$Q_{\text{either regen. pair}} \approx 4.72 \text{ X } 10^{-3}$$

The probability of a power failure was found as follows. The reliability of the commercial power system over a year was assumed to be 0.85. The corresponding unreliability would be 0.15. The MTBF of the backup power system was said to be 17520 hrs, and MTTR is 7.5 hr. Therefore, the unreliability of the power system would be:

$$Q_{\text{power}} = (0.15)\ (1-e^{\frac{-7.5}{17520}}) \approx 3.64 \text{ X } 10^{-4}$$

The probability of a site with channel breakout totally failing in one year would be approximately the sum of $Q_{\text{power}} + Q_{\text{either regen pair}} + Q_{\text{either radio pair}} + Q_{\text{either TDM pair}} + Q_{\text{any 3 PCM}} = 0.011$.

The probability of a through repeater totally failing in one year is approximately the sum of $Q_{\text{power}} + Q_{\text{either radio pair}} \approx 9.8 \text{ x } 10\text{-}3$.

Since the reference system was assumed to be 10 sites with channel breakout and 5 through repeaters, the probability of any disruption of end-to-end communications in one year would be approximately:

$$Q_{system} = (10)\,(0.011) + (5)\,(9.8 \times 10^{-3}) \approx 0.16$$

Therefore, the odds are 6 to 1 against any system disruptions occurring in one year due to maintenance problems.

(2) Reliability of Different Site Configurations. Occasionally, maintenance personnel will not be able to maintain a site on a regular basis. It is therefore important to have an indication of how long the site will operate without maintenance. It was assumed that a site could not be maintained for one week and all equipment was operational at the start of that period.

The probability of 3 given PCMs failing in one week (168 hrs) is found by the following equation:

$$Q_{3\ PCM} = (1-e^{\frac{-168}{4500}})\,(1-e^{\frac{-168}{4500}})\,(1-e^{\frac{-168}{4500}})$$

$$Q_{3\ PCM} \approx 4.92 \times 10^{-5}$$

Therefore, the probability of any 3 of the 18 PCM units failing in one week is approximately:

$$Q_{any\ 3\ PCM} \approx (816)\,(4.92 \times 10^{-5}) = 0.04$$

The probability of both a primary and standby TDM failing one week would be:

$$Q_{2\ TDM} = (1-e^{\frac{-168}{3500}})\,(1-e^{\frac{-168}{3500}}) \approx 2.2 \times 10^{-3}$$

Therefore, the probability of either TDM redundancy pair failing in one week is approximately:

$$Q_{either\ TDM\ pair} \approx (2)\,(2.2 \times 10^{-3}) \approx 4.4 \times 10^{-3}$$

The probability of either radio redundancy pair failing in one week would be approximately:

$$Q_{either\ radio\ pair} \approx (2)\,(1-e^{\frac{-168}{3000}})\,(1-e^{\frac{-168}{3000}}) \approx 5.93 \times 10^{-3}$$

Since the MTBF of the regenerator equipment was assumed to be equal to the MTBF of the radios, the probability of either regenerator redundancy pair failing would be:

$$Q_{\text{either regen pair}} = 5.93 \times 10^{-3}$$

The probability of the backup power unit failing during one week would be:

$$Q_{\text{B/U power}} = (1-e^{\frac{-168}{17520}}) = 9.54 \times 10^{-3}$$

As was stated before, the probability of a site with channel breakout failing to operate is approximately the sum of $Q_{\text{any 3 PCM}} + Q_{\text{either TDM pair}} + Q_{\text{either radio pair}} + Q_{\text{B/U power}} = 0.06$.

Therefore, the odds are 16 to 1 against the site with channel breakout failing even if it is not maintained for one week.

The probability of a through repeater failing in one week would be approximately the sum of $Q_{\text{either radio pair}} + Q_{\text{either regen pair}} + Q_{\text{B/U power}} \approx 0.02$.

Therefore, the odds are approximately 50 to 1 against the through repeater failing even if it is not maintained for a week.

1-4. Conclusion. It is therefore concluded that the maintenance concept results in acceptable maintainability/reliability for the PCM/TDM microwave transmission system.

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